Structure of Underlying-Event and Min-Bias Events

P. Skands (CERN)

Mín-Bías and UE

Minimum-Bias

- High-Statistics reference laboratory
- Ideal for studies of non-pQCD properties
  - *Including Fragmentation, diffraction, beam remnant blowup, ...*
- All Soft → 10-20% precision is probably the <u>best</u> we can do
  - *Model power = simultaneous description of many observables*

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Underlying Event

- Pedestal effect: jet events more active than minimum-bias
- Dominating model: multiple parton interactions
- Beware large fluctuations *(cf., e.g., ATLAS RMS measurement)*

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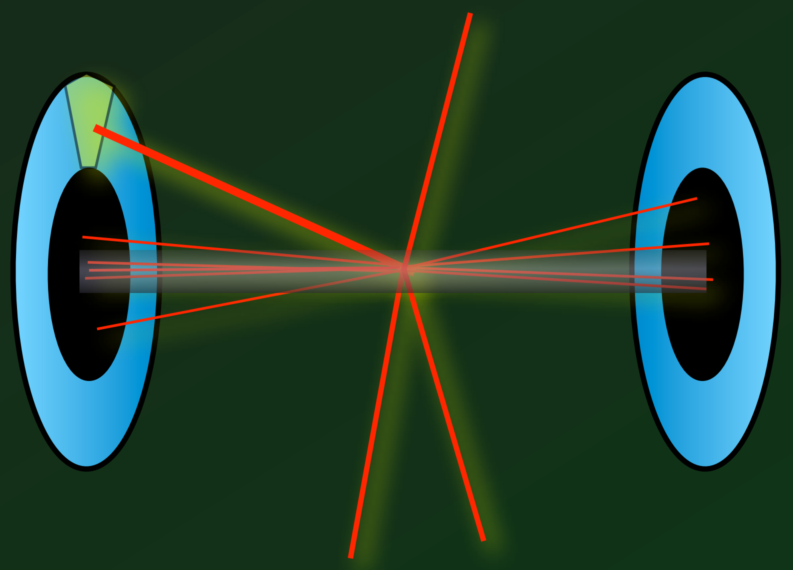
+ Phenomenology → Theory?

MB Terminology



Min-Bias, Zero Bias, etc.

= Experimental trigger conditions

"Theory for Min-Bias"?

Really = Model for ALL INELASTIC

But … how can we do that?

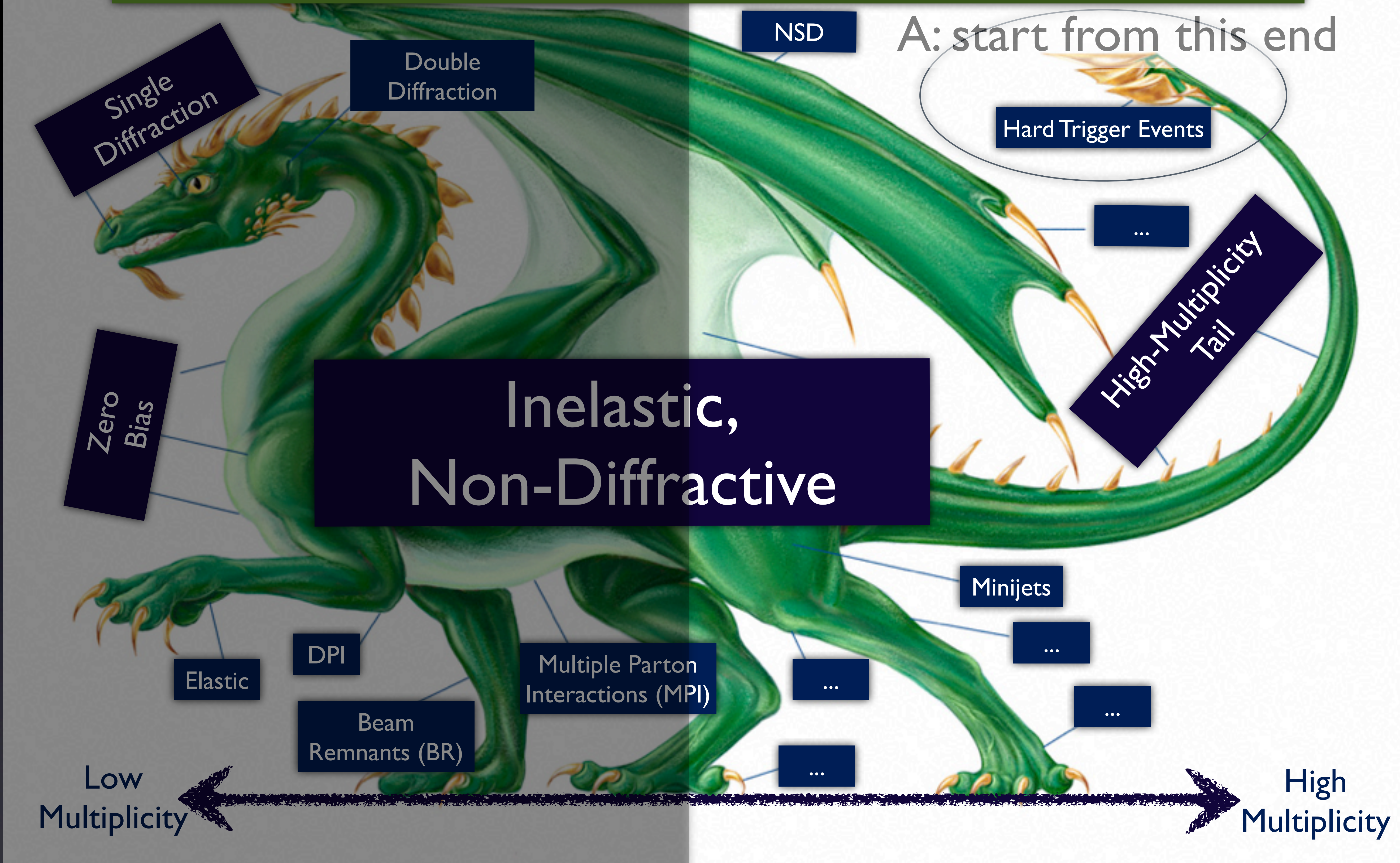
… in minimum-bias, we typically do not have a hard scale, wherefore *all* observables depend significantly on IR physics …

PS, "the Perugia tunes", arXiv:1005.3457

A) Start from perturbative model (dijets) and extend to IR

B) Start from soft model (Pomerons) and extend to UV

Dissect & Model



MPI

Multiple Perturbative Parton-Parton Interactions

A) Start from perturbative model (dijets) and extend to IR

pQCD

2→2

= Sum of

$qq' \to qq'$
$q\bar{q} \to q'\bar{q}'$
$q\bar{q} \to gg$
$qg \to qg$
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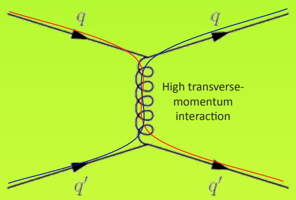
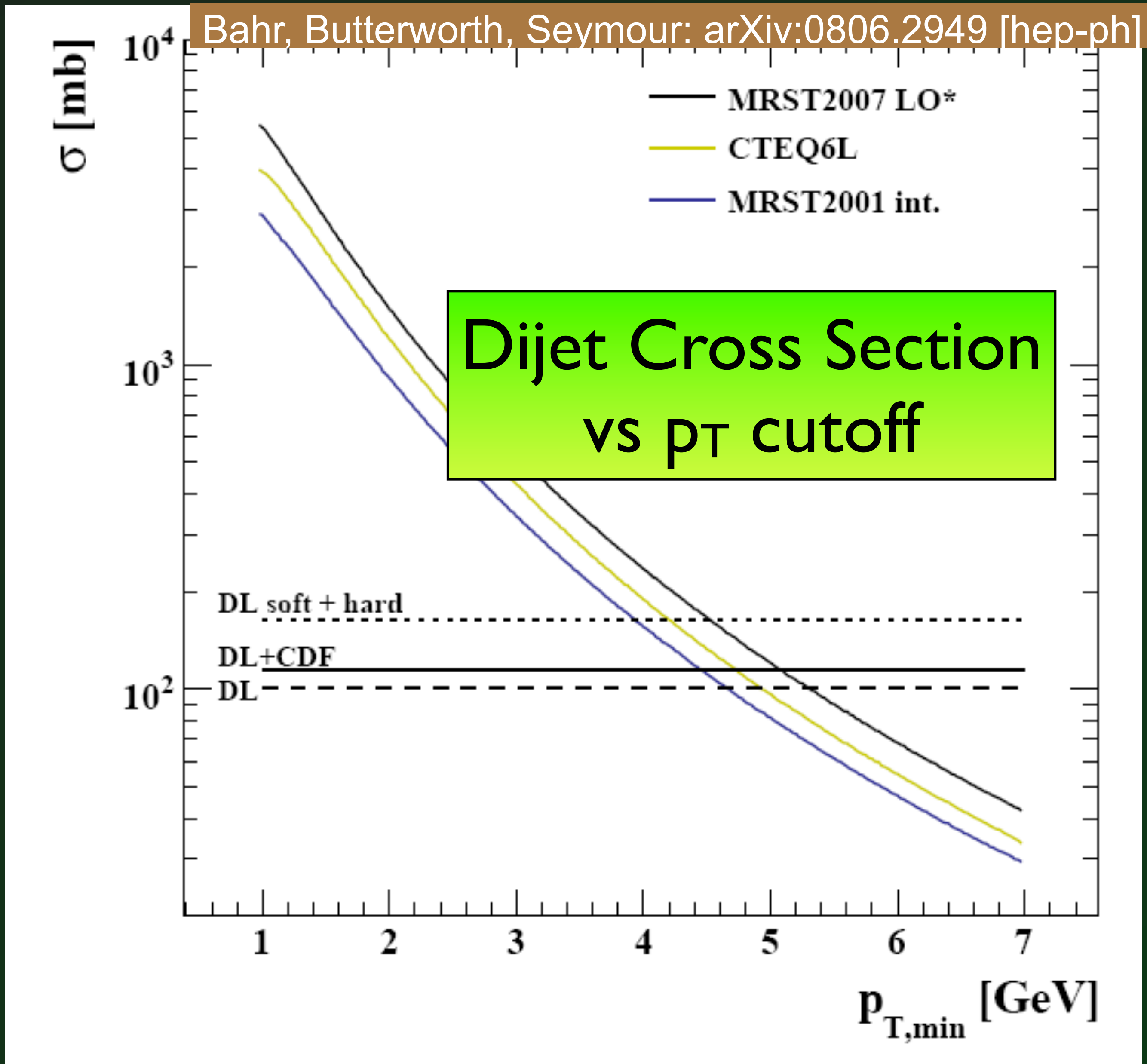
≈ Rutherford
(t-channel gluon)





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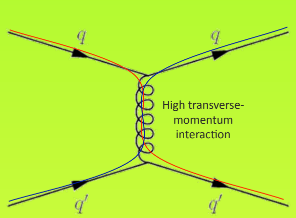

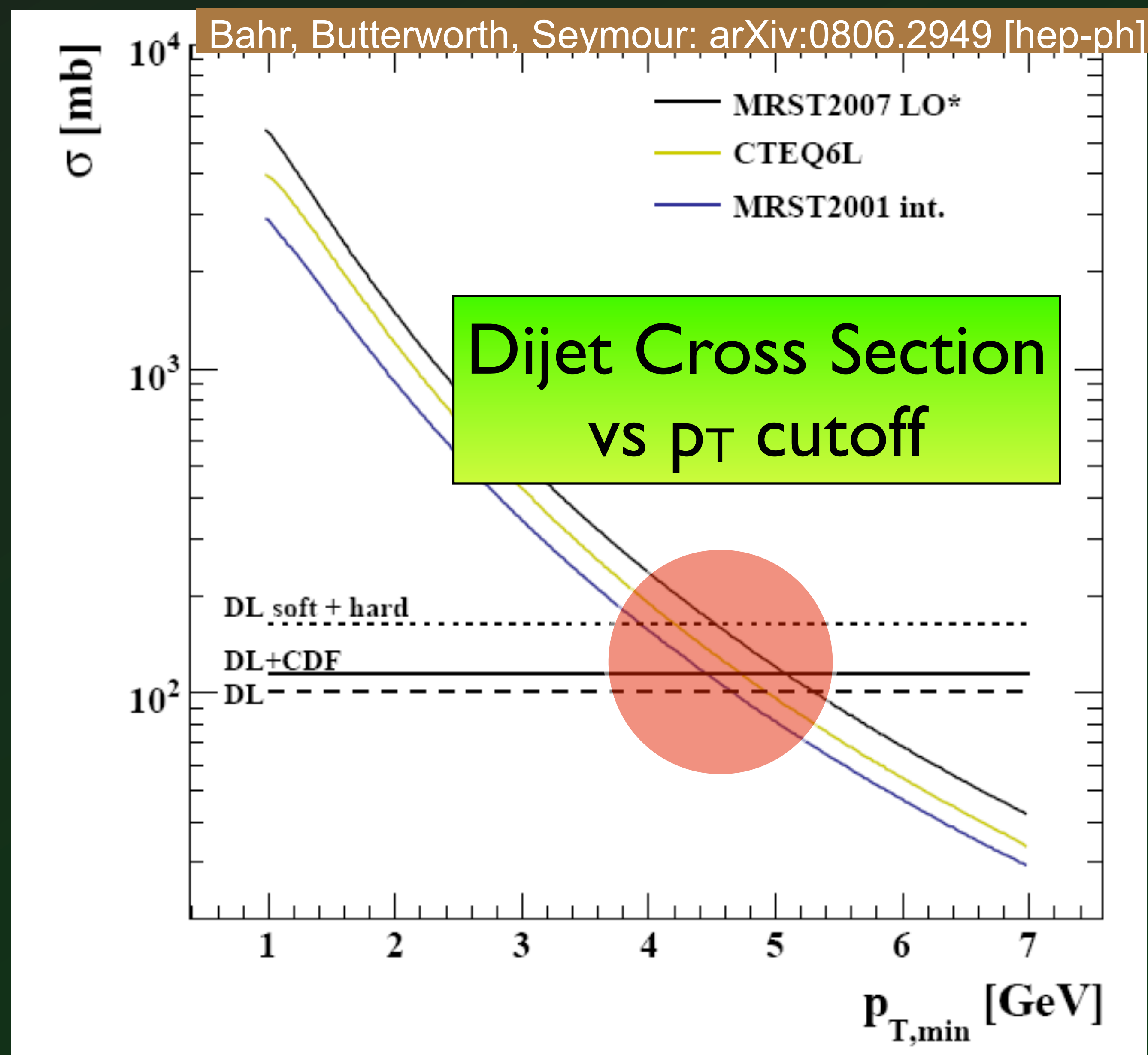

Becomes larger than total pp cross section?

At $p_\perp \approx 5$ GeV

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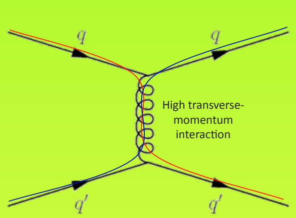

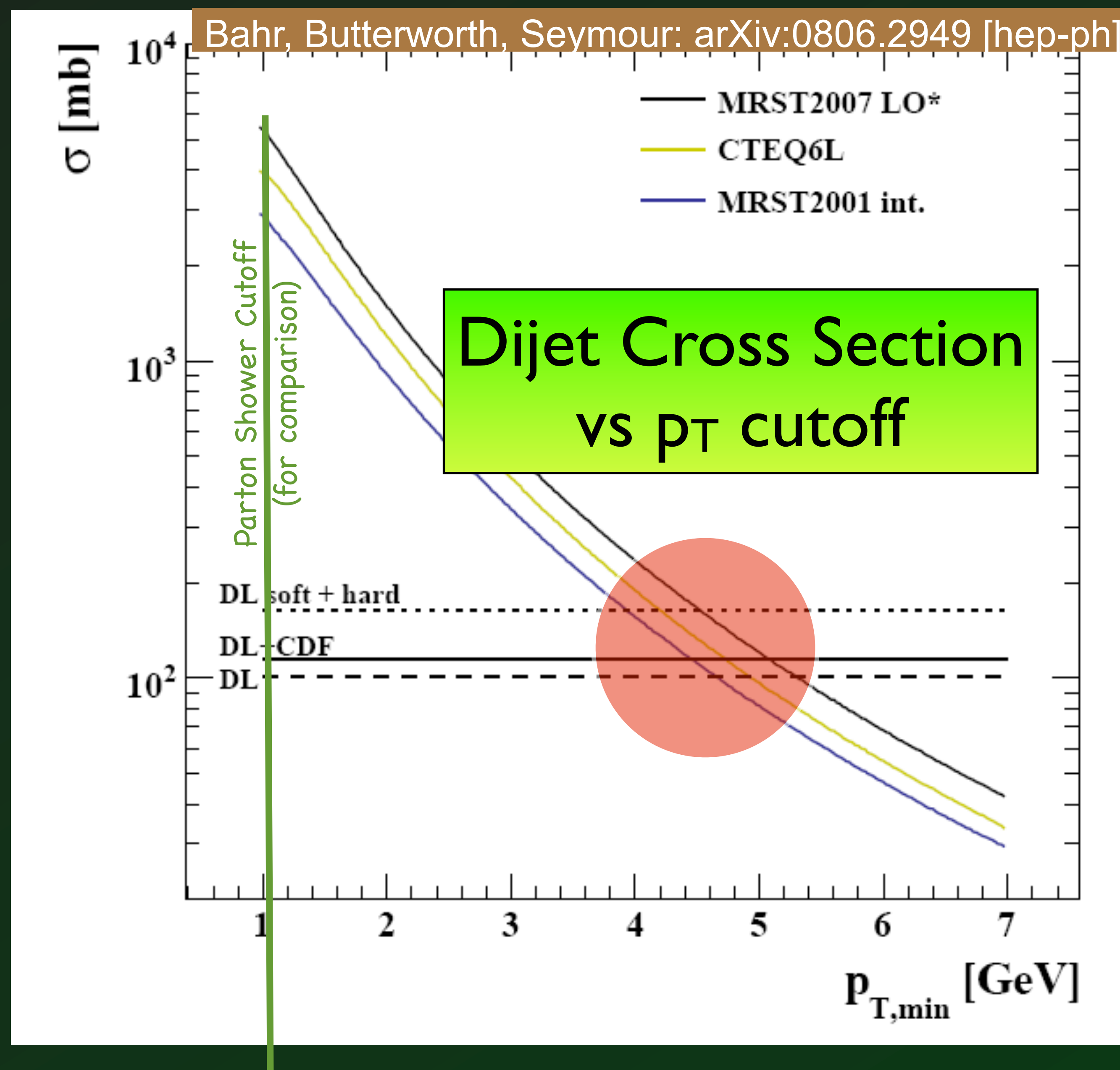

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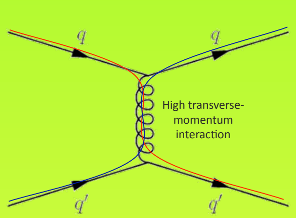

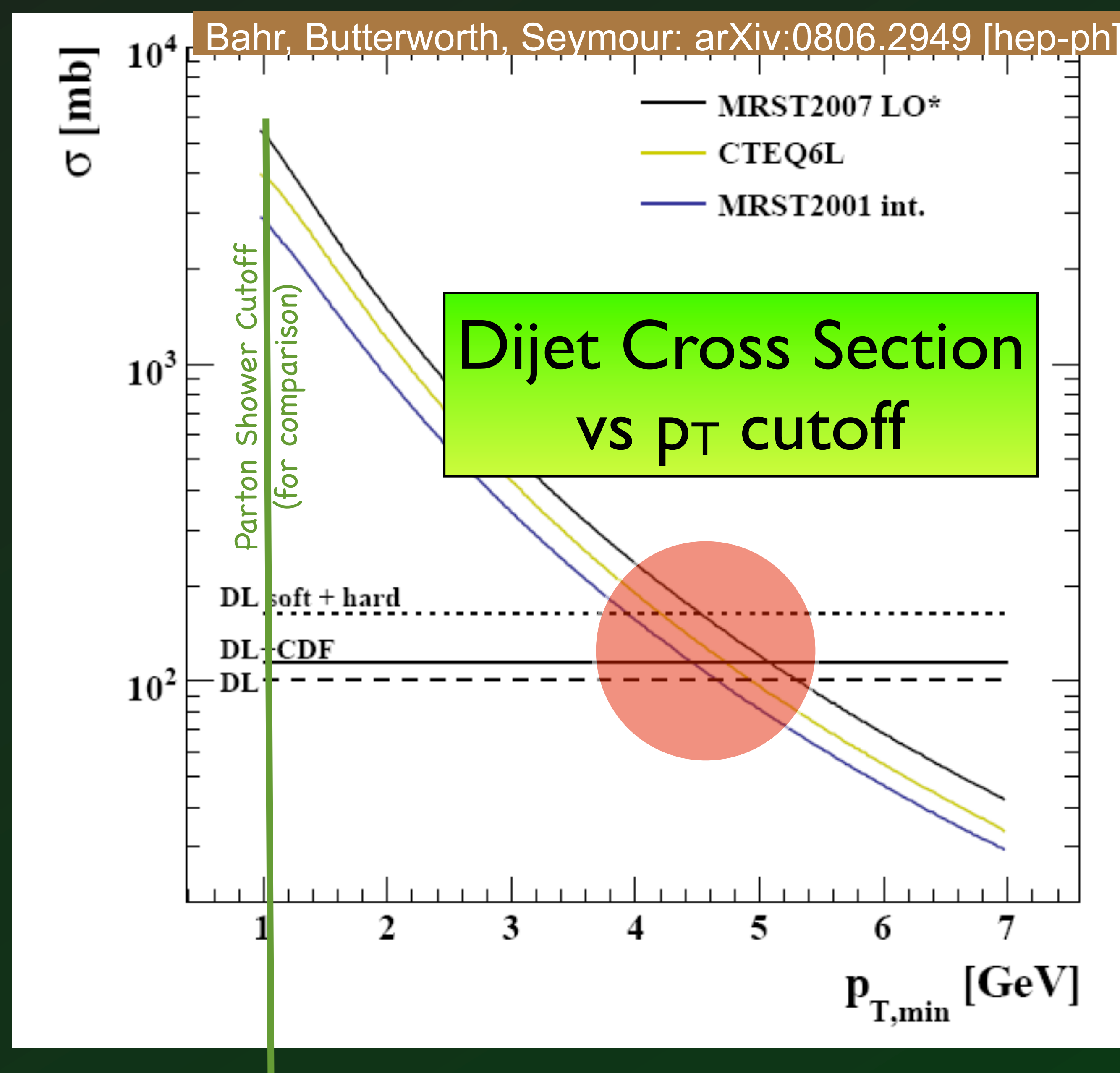

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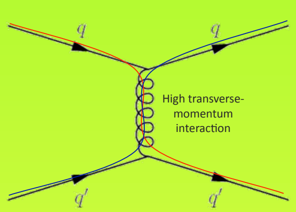

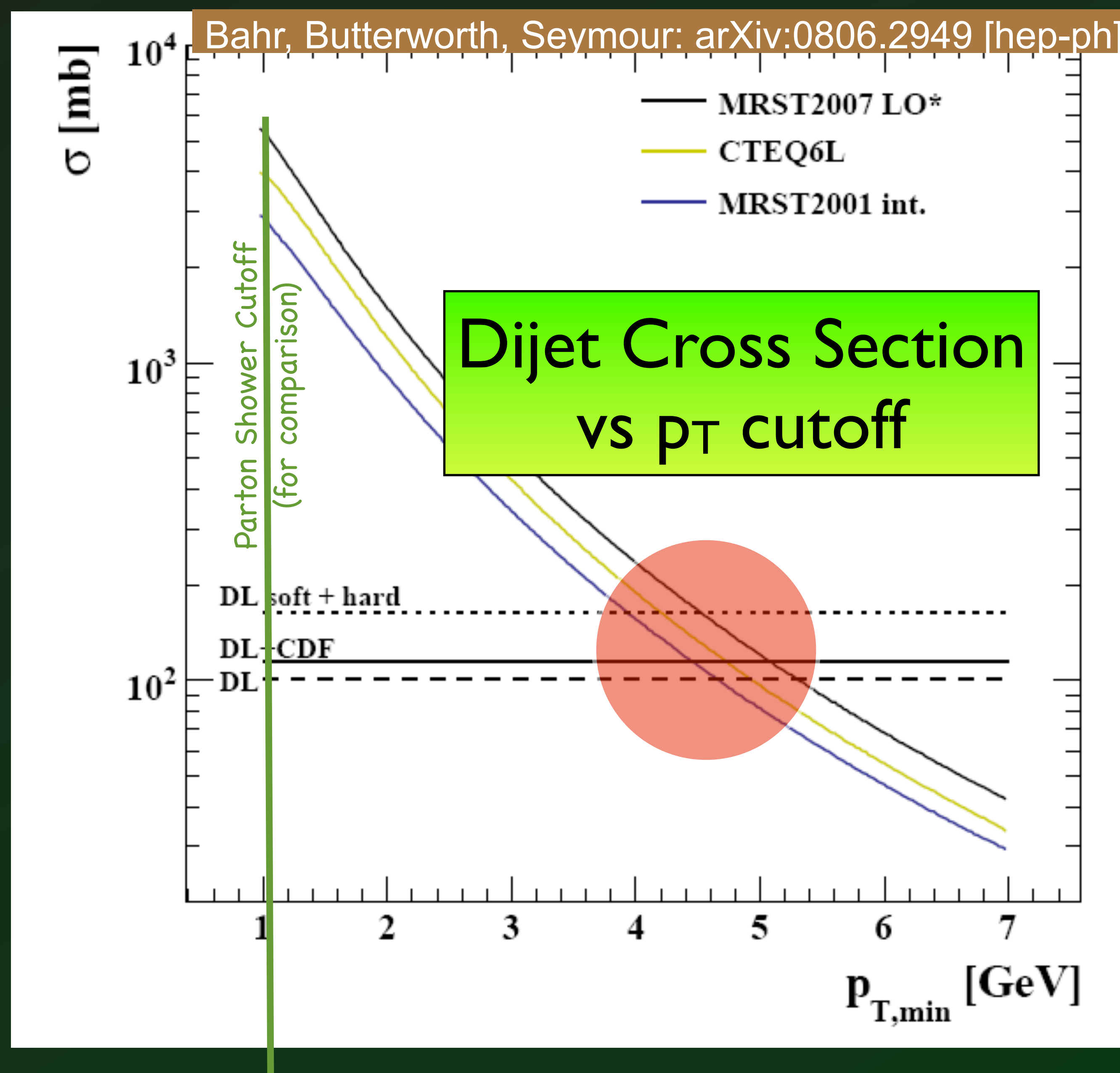

Dijet Cross Section vs p_T cutoff

Becomes larger than total pp cross section?

At $p_\perp \approx 5$ GeV

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→ Resum dijets? Yes → MPI!

$\sigma_{\text{parton-parton}} > \sigma_{\text{proton-proton}}$

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What does $\sigma_{\text{proton-proton}}$ count?

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$$\frac{\mathrm{d}\sigma_{2j}}{\mathrm{d}p_\perp^2} = \sum_{i,j,k} \int \mathrm{d}x_1 \int \mathrm{d}x_2 \int \mathrm{d}\hat{t}\ f_i(x_1,\mu_F^2)\, f_j(x_2,\mu_F^2)\, \frac{\mathrm{d}\hat{\sigma}_{ij\to kl}}{\mathrm{d}\hat{t}}\, \delta\left(p_\perp^2 - \frac{\hat{t}\hat{u}}{\hat{s}}\right) \propto \frac{1}{p_{\perp\mathrm{min}}^2}$$

(neglecting pdf dependence and α_s running)

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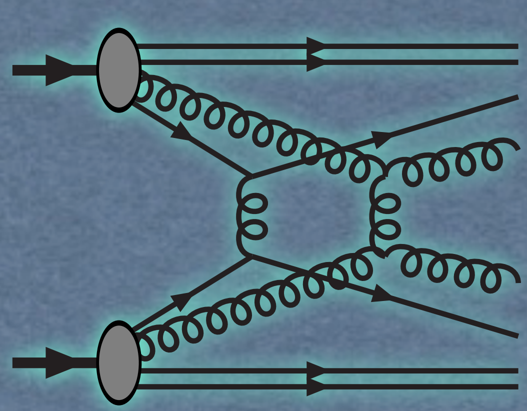
Inclusive number of PARTON-PARTON interactions

1 pp collision → counts once in σ_{pp}



2 parton-parton collisions → Counts twice in $\sigma_{\text{parton-parton}}$

How many?

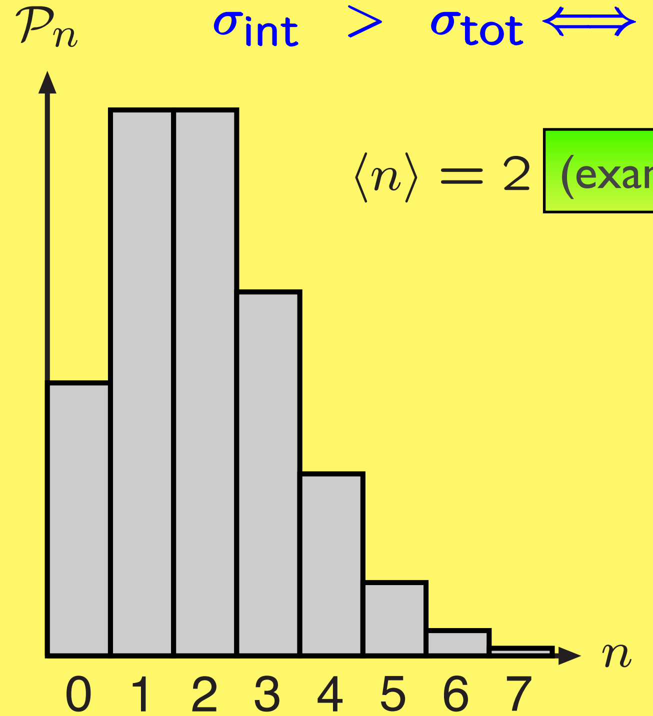
Naively $\langle n_{2\to 2}(p_{\perp\min})\rangle = \dfrac{\sigma_{2\to 2}(p_{\perp\min})}{\sigma_{\mathrm{tot}}}$ ⟵ parton-parton ⟵ proton-proton

Interactions independent (naive factorization) → Poisson

$$\sigma_{\mathrm{tot}} = \sum_{n=0}^{\infty} \sigma_n$$

$$\sigma_{\mathrm{int}} = \sum_{n=0}^{\infty} n\,\sigma_n$$

$$\sigma_{\mathrm{int}} > \sigma_{\mathrm{tot}} \Longleftrightarrow \langle n\rangle > 1$$



$$\mathcal{P}_n = \frac{\langle n\rangle^n}{n!}\, e^{-\langle n\rangle}$$

Real Life

Momentum (x) cons
suppresses high-n tail

+ physical correlations →
not simple product

Naíve Factorization: σ_{eff}

Interactions independent (naive factorization) → Poisson

Often used for simplicity

(i.e., assuming corrections are small / suppressed)

CDF Collaboration, Phys. Rev. Lett. 79 (1997) 584

Measurement of Double Parton Scattering in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ Tev

The double parton scattering (DP) process [1], in which two parton-parton hard scatterings take place within one $\overline{p}p$ collision, can provide information on both the distribution of partons within the proton and on possible parton-parton correlations, topics difficult to address within the framework of perturbative QCD. The cross section for DP comprised of scatterings A and B is written

$$\sigma_{\rm DP} \equiv \frac{\sigma_A \sigma_B}{\sigma_{\rm eff}}, \qquad (1)$$

with a process-independent parameter $\sigma_{\rm eff}$ [2–5]. This expression assumes that the number of parton-parton interactions per collision is distributed according to Poisson statistics [6], and that the two scatterings are distinguishable [7]. Previous DP measurements have come

$\sigma_{eff} \approx$ "first moment" of MPI distributions
First rough characterization of MPI

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σ_{eff} ≈ "first moment" of MPI distributions
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But careful, σ_{eff} implicitly relies on factorized approximation!

Extracting σ_{eff} is fine, but also need model-independent <u>physical observables</u>

From partons to hadrons

Initial State: Multi-Parton Distributions

Beyond naive factorization: *correlations in flavor, impact parameter, and momentum (+ color?) → make ansätze (different in different MC programs)*

⇒ Still, can model/predict **Multiple <u>perturbative</u>** (higher-twist) **interaction rates** using (mostly) **pQCD**

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Still a long way to the IR **[Recall MB ≈ All soft]**

Soft Interactions ≈ *(Dressed) partonic (?) scattering down to zero p_T?*

Coherent soft interactions: *diffraction and gaps*

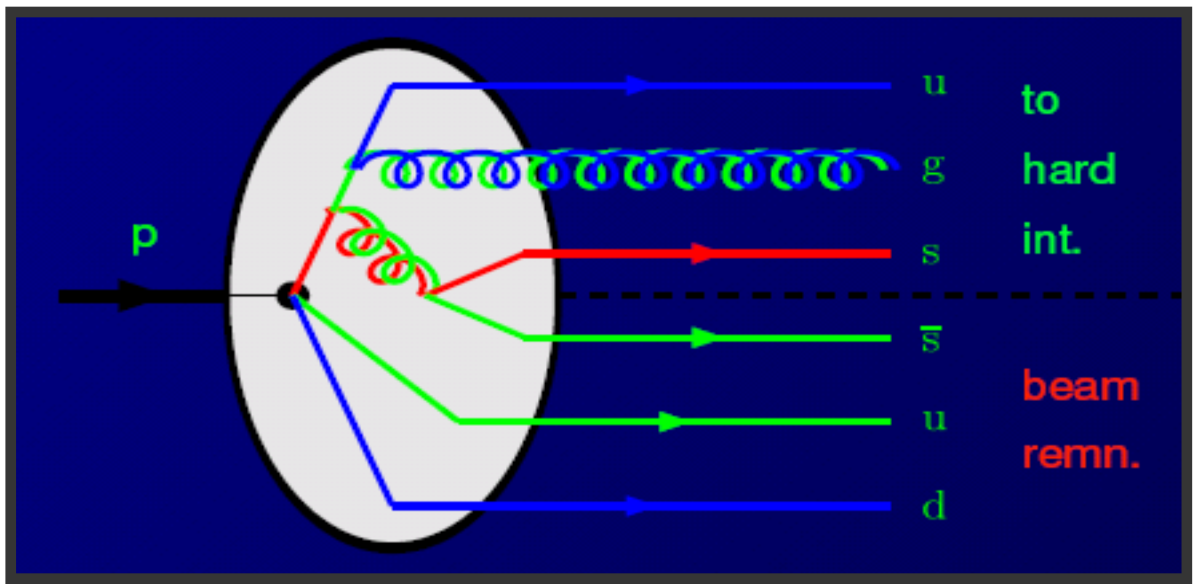
Confinement & Hadronization: *corrections to leading-N_C ?*

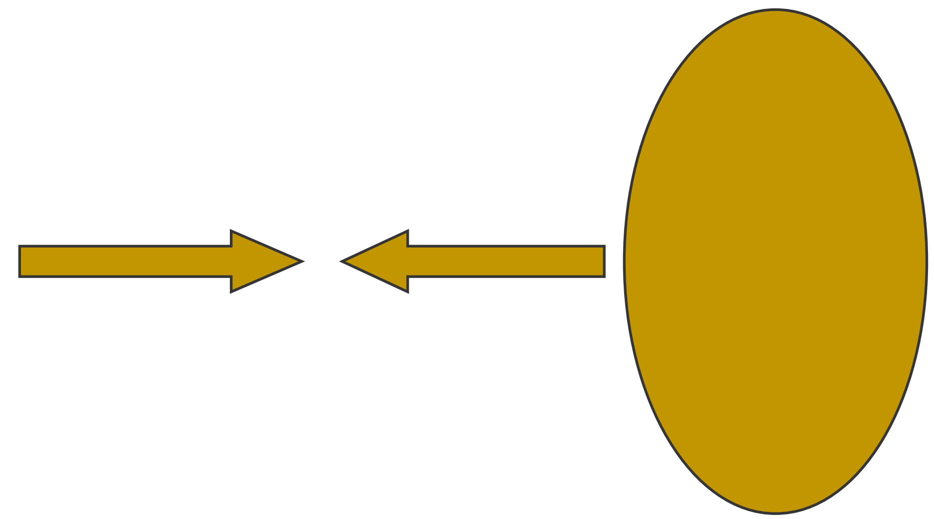
Additional non-perturbative phenomena? Color reconnections, string interactions, Bose-Einstein, hydro flow, … ?

= what we had at LEP + a bunch more …

Questions

Multi-Parton PDFs





How are the initiators and remnant partons correllated?

- in impact parameter?
- in flavour?
- in x (longitudinal momentum)?
- in k_T (transverse momentum)?
- in colour (→ string topologies!)
- What does the beam remnant look like?
- (How) are the showers correlated / intertwined?

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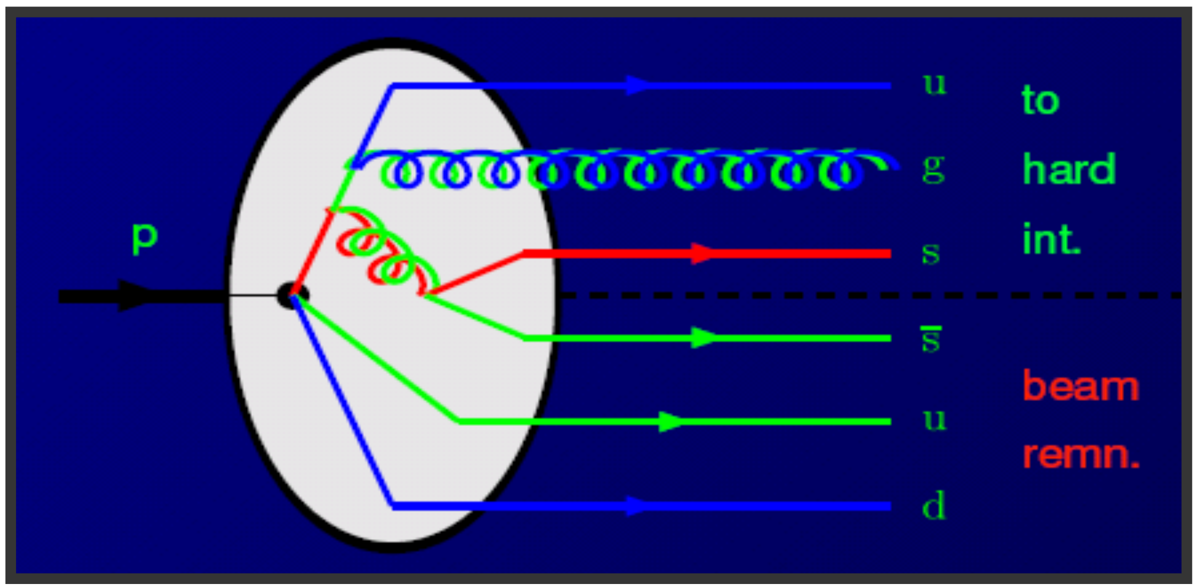

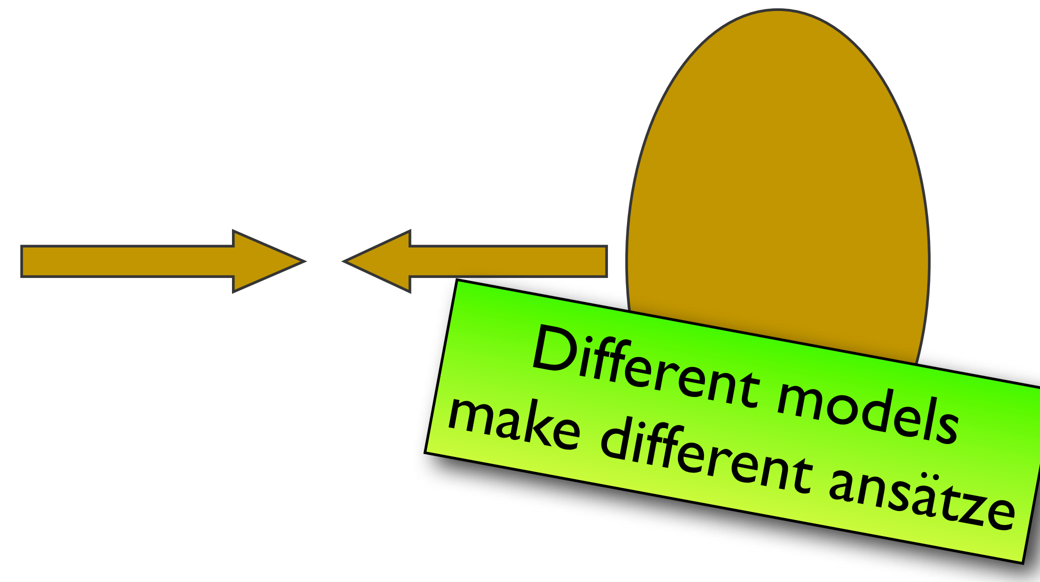

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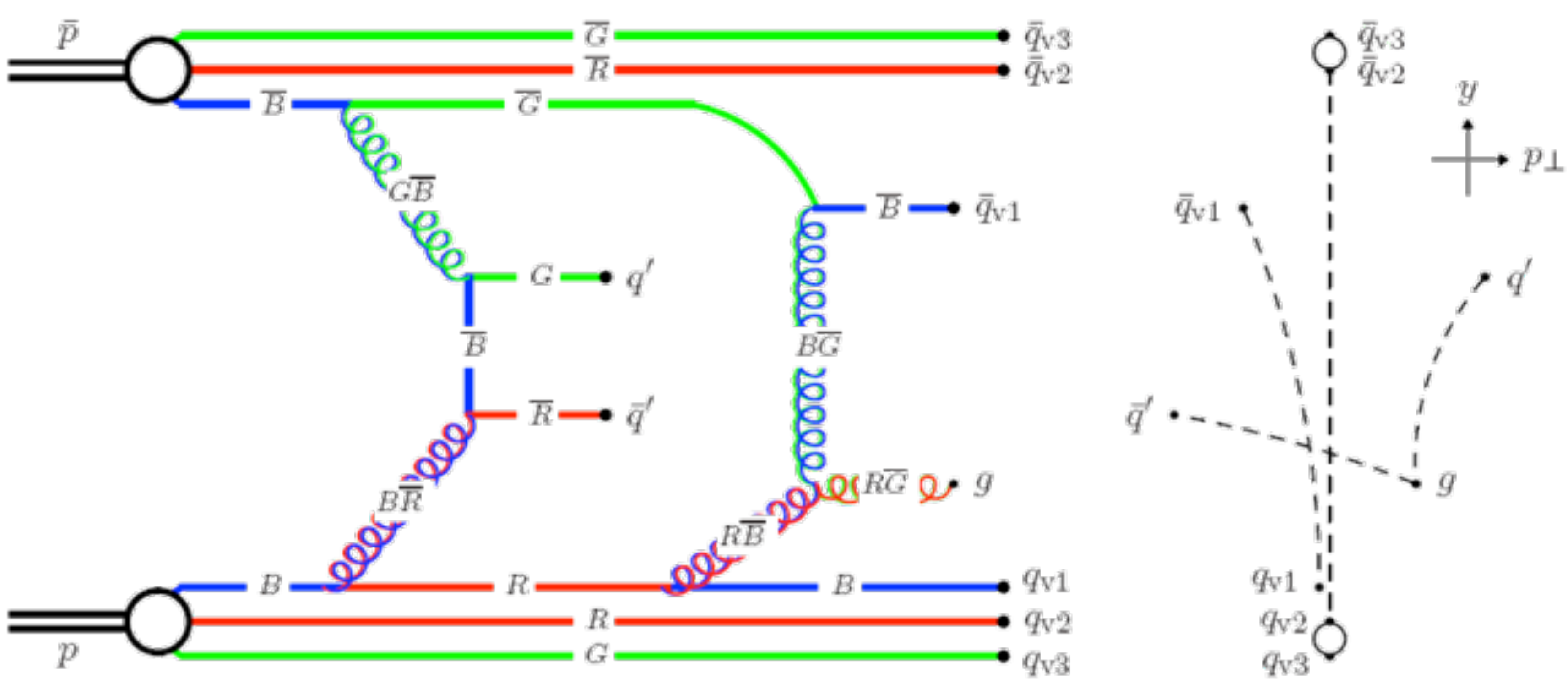
Colour and the UE

Each MPI exchanges color between the beams

- ► The colour flow determines the hadronizing string topology
  - Each MPI, even when soft, is a color spark
  - Final distributions crucially depend on color space



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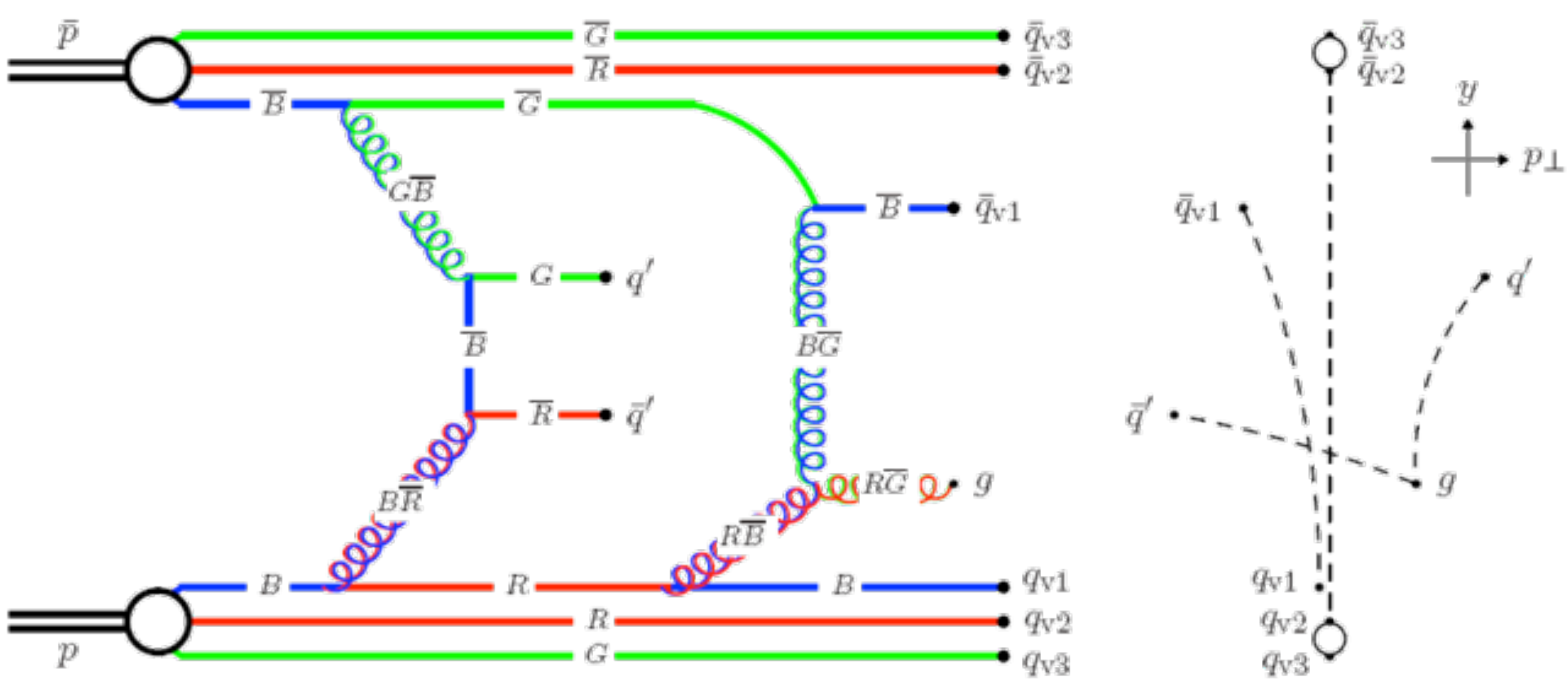

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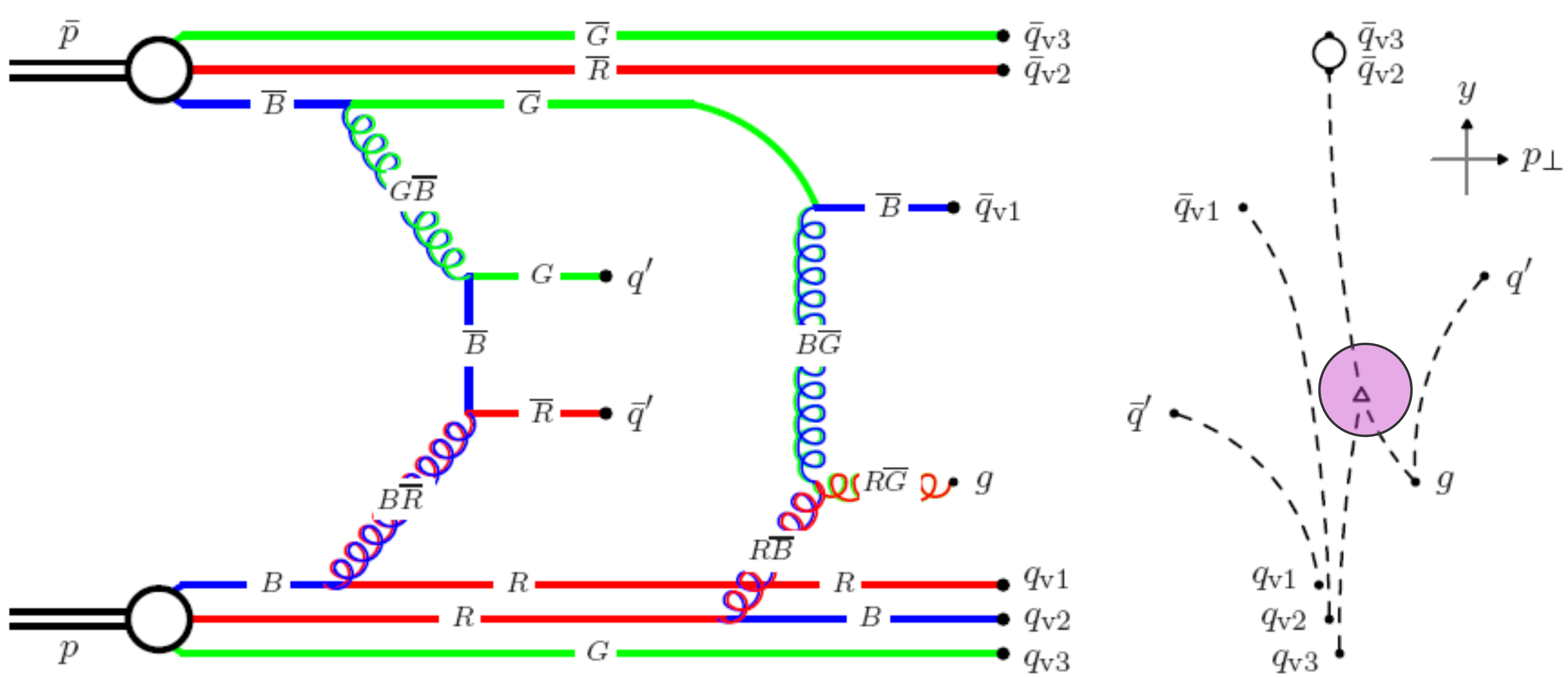

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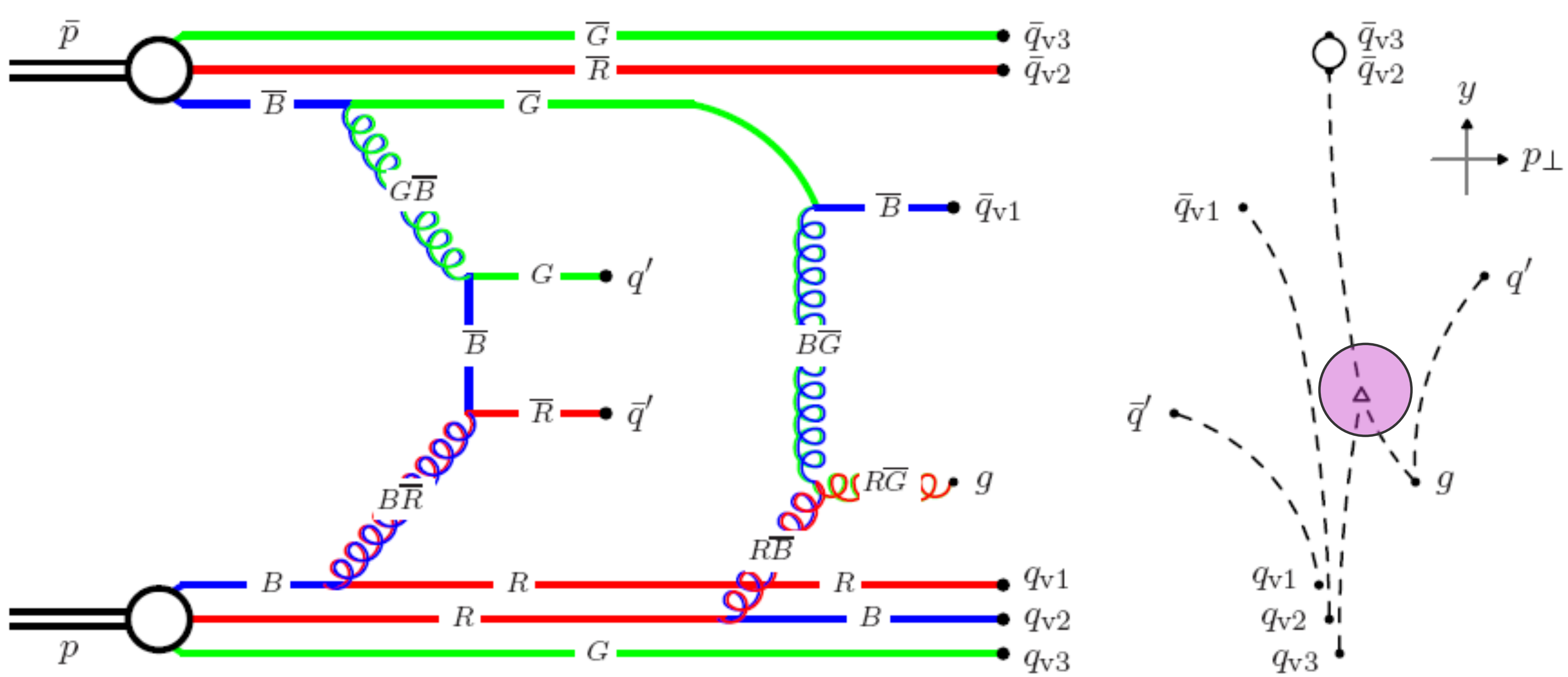

Note: this just color **connections**, then there may be color **reconnections** too

Taking an Organized View

1. Where is the energy going?

Note: only linearized Sphericity is IR safe

Sum(pT) densities, event shapes, mini-jet rates, energy flow correlations… ≈ *sensitive to pQCD + pMPI*

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IR Sensitive

More IR Sensitive

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3. What kind of tracks?

Strangeness per track, baryons per track, beam baryon asymmetry, … s-baryons per s, multi-s states, s-sbar correlations, …. ≈ sensitive to details of hadronization

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More IR Sensitive

Example: Radiation vs MPI

- What is producing the tracks?
  - Is it **Radiation**? (tends to produce partons close in phase space)
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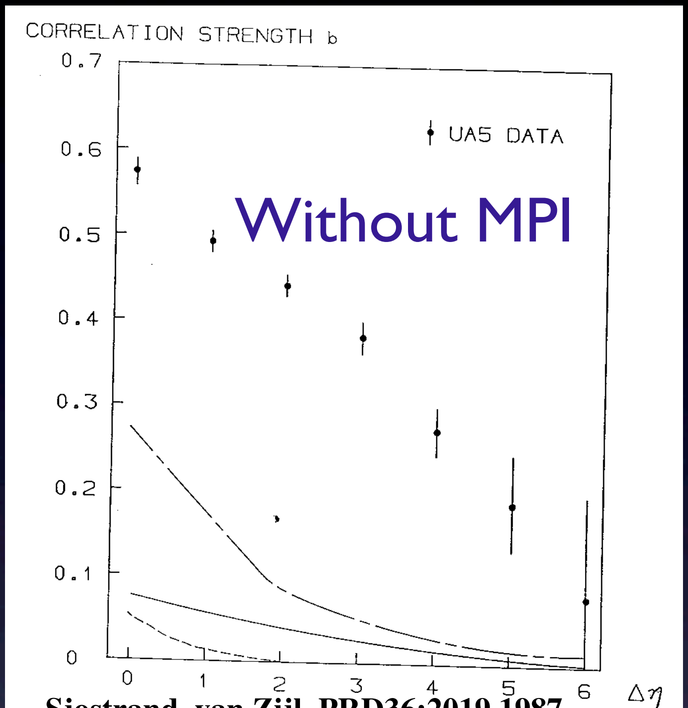

Sjostrand, van Zijl, PRD36:2019,1987.

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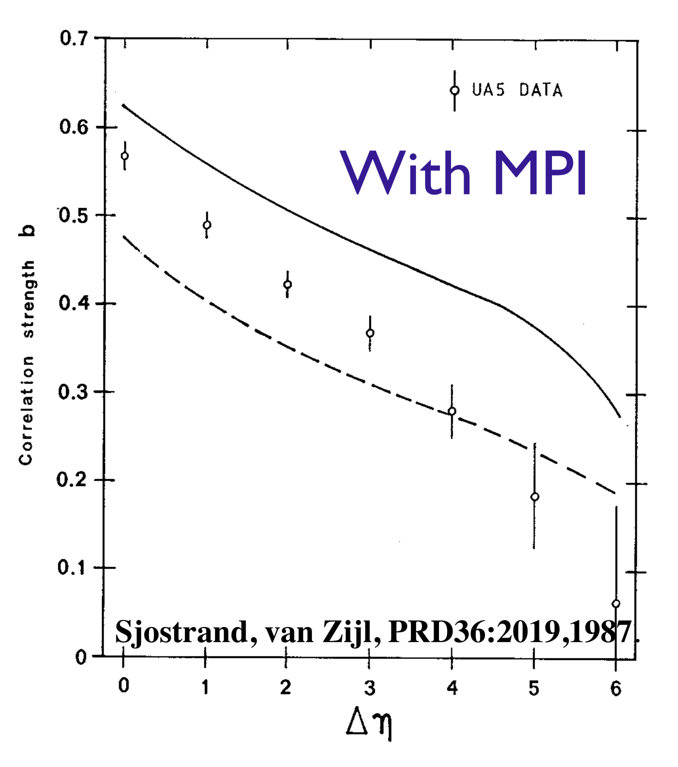

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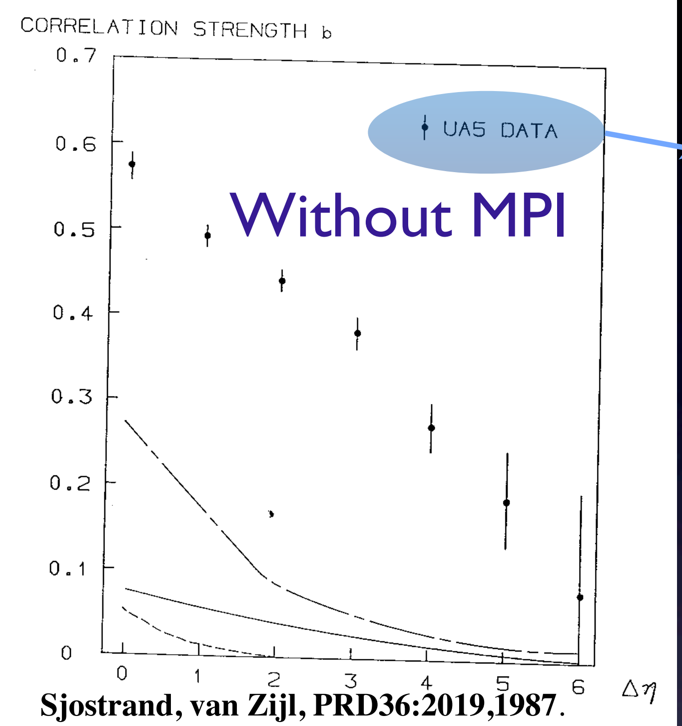

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b Not measured at Tevatron

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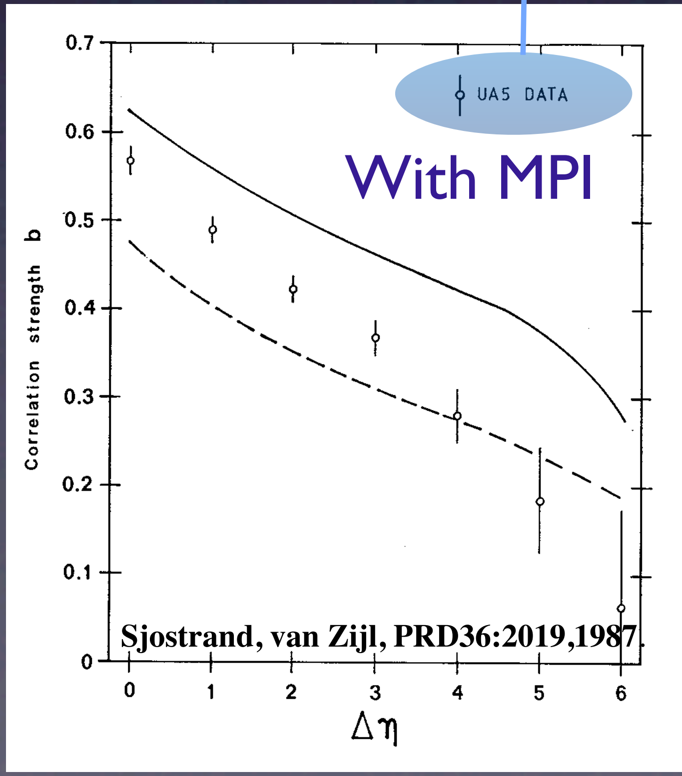

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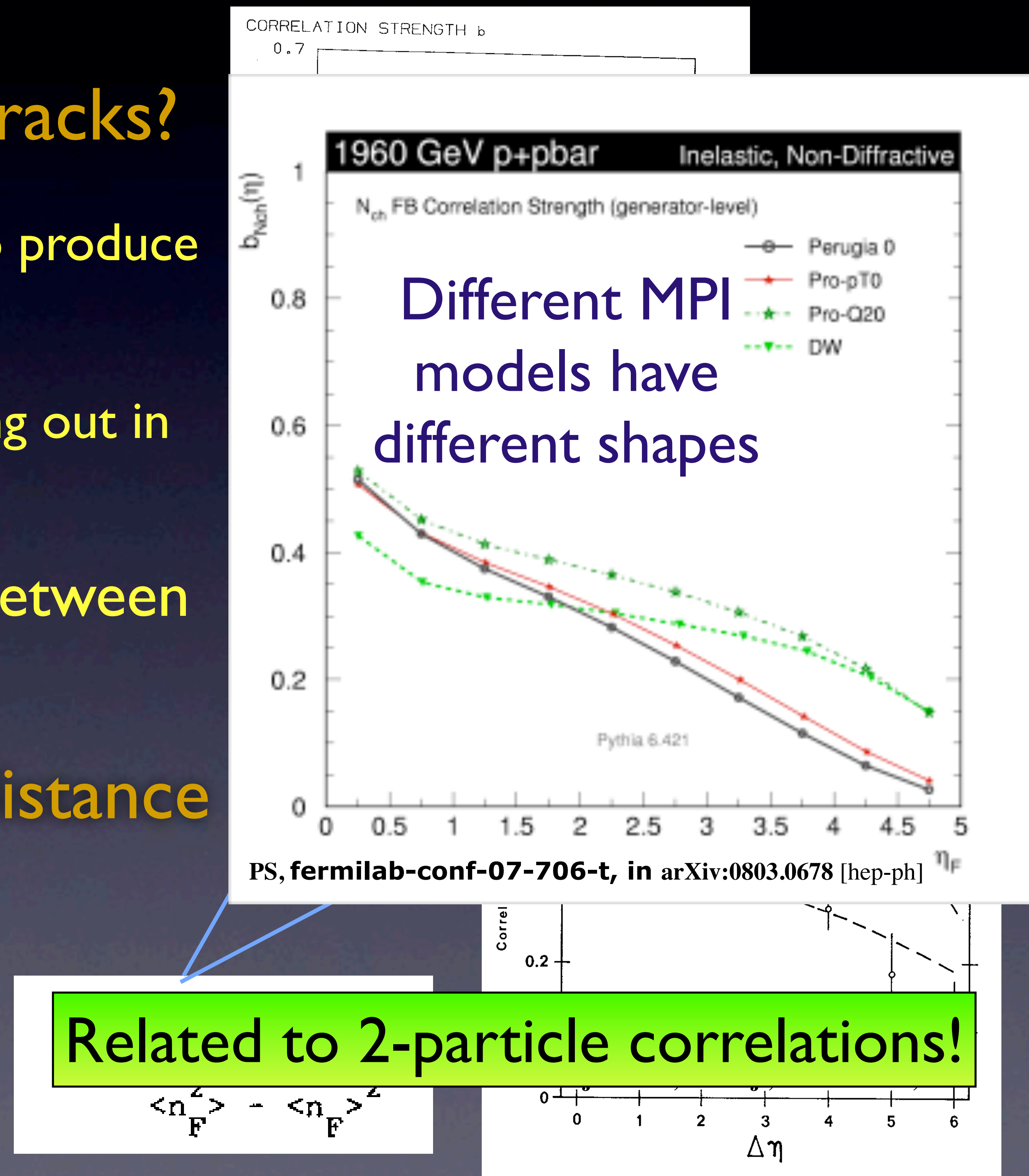

Related to 2-particle correlations!

Action Items

September 2010

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Hard diffraction included in PYTHIA8
+ being included in HERWIG++ and SHERPA
+ more later?

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3. Need better understanding of E-scaling

E-scaling allows to consolidate measurements from different colliders (not the least LEP) → powerful cross check on physics model

While waiting for better model of diffraction, isolate and continue testing non-diffractive tail of MB + Systematically compare to LEP (jet fragmentation) & UE

Energy Scaling

Can we be more general than this-tune-does-this, that-tune-does-that?

- Yes
  - *The new automated tuning tools allow us to get an Unbiased optimization at each collider separately*
- Critical for this task:
  - *"Comparable" data set at each different collider energy*

Example on next pages using PYTHIA 6, but applies to any model

Scaling according to Holger

(Schulz)

MCnet/LPCC Summer Student *(+co-author of Professor)*

Used CDF, UA5, and ATLAS data

- $P(N_{ch})$, dN_{ch}/dp_T, $<p_T>(N_{ch})$
  - + *can even focus on $N_{ch} \geq 6$ sample separately!*
- From 630 GeV to 7 TeV (we would have liked to add STAR at 200 GeV, but we did not have a complete obs set from them)

Scaling according to Holger

(Schulz)

MCnet/LPCC Summer Student *(+co-author of Professor)*

Used CDF, UA5, and ATLAS data

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From 630 GeV to 7 TeV (we would have liked to add STAR at 200 GeV, but we did not have a complete obs set from them)

Reduce model to 3 main parameters: *Starting point = Perugia 0*

1. Infrared Regularization Scale	p_{Tmin}	*PARP(82)*
2. Proton Transverse Mass Distributions	μ	*PARP(83)*
3. Strength of Color Reconnections	CR	*PARP(78)*

Infrared Regularization

Independent tunings compared to Perugia 0

No large deviation from the assumed functional form
(E.g., Tunes A, DW, Perugia-0 use $\mathrm{Exp}_{\mathrm{PARP(90)}} = 0.25$)

cf., also, e.g., CMS, studies by R. Field

&

Sjöstrand & van Zijl, PRD36(1987)2019

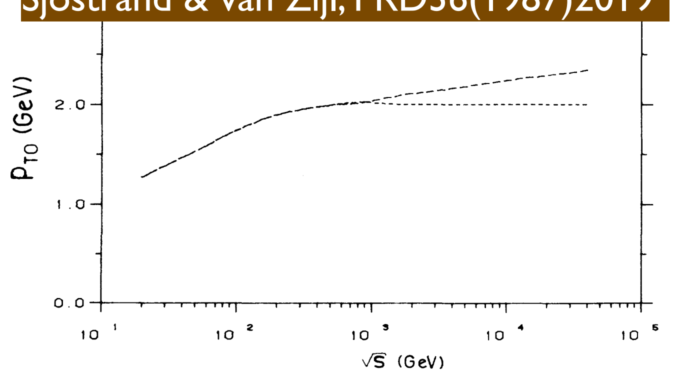
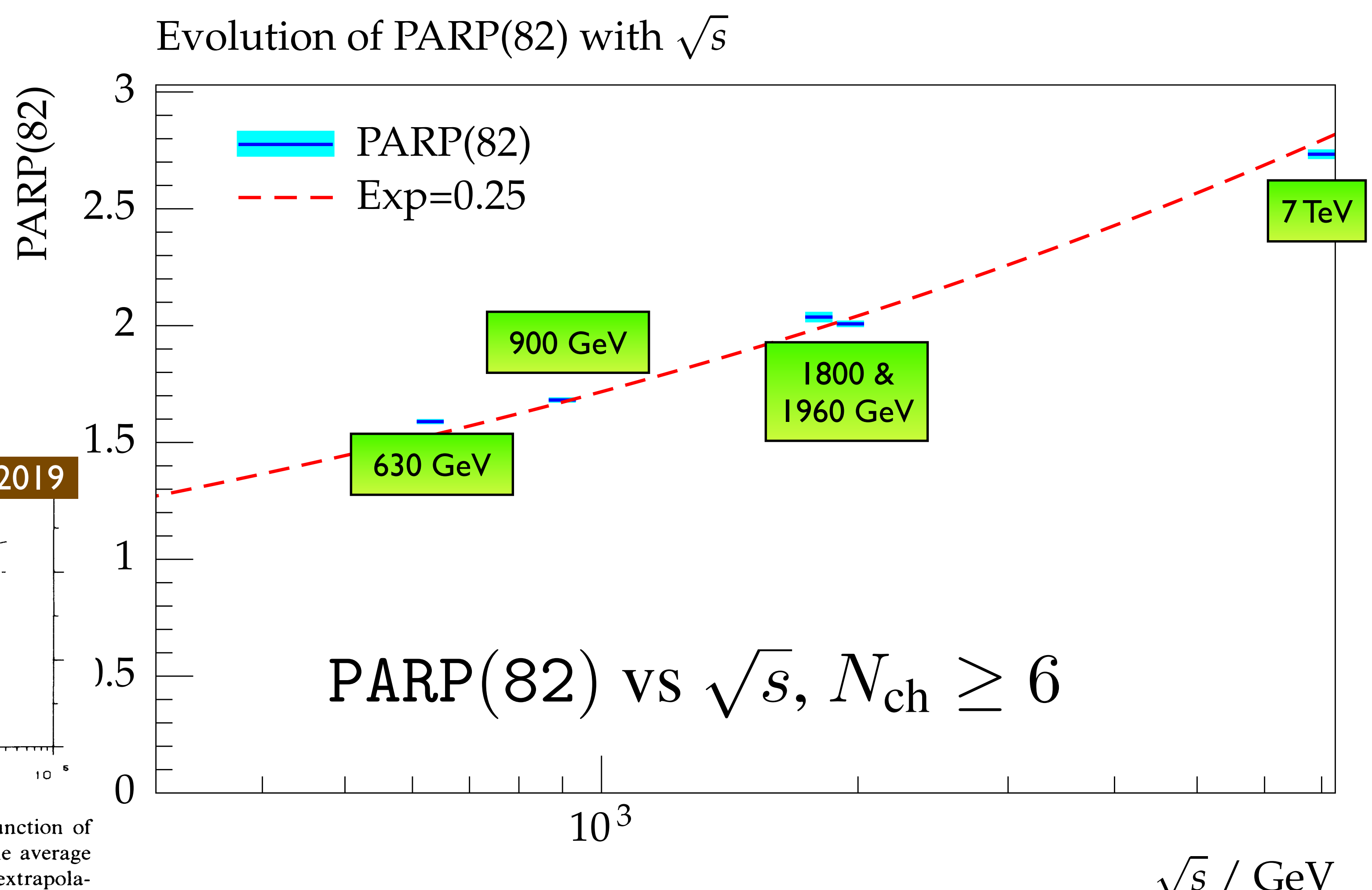


FIG. 8. Values for the cutoff parameter p_{T0} as a function of c.m. energy , as determined from comparisons with the average charged multiplicity. Dashed line, with a logarithmic extrapolation to higher energies, Eq. (38); dotted line, if assumed constant above 900 GeV.



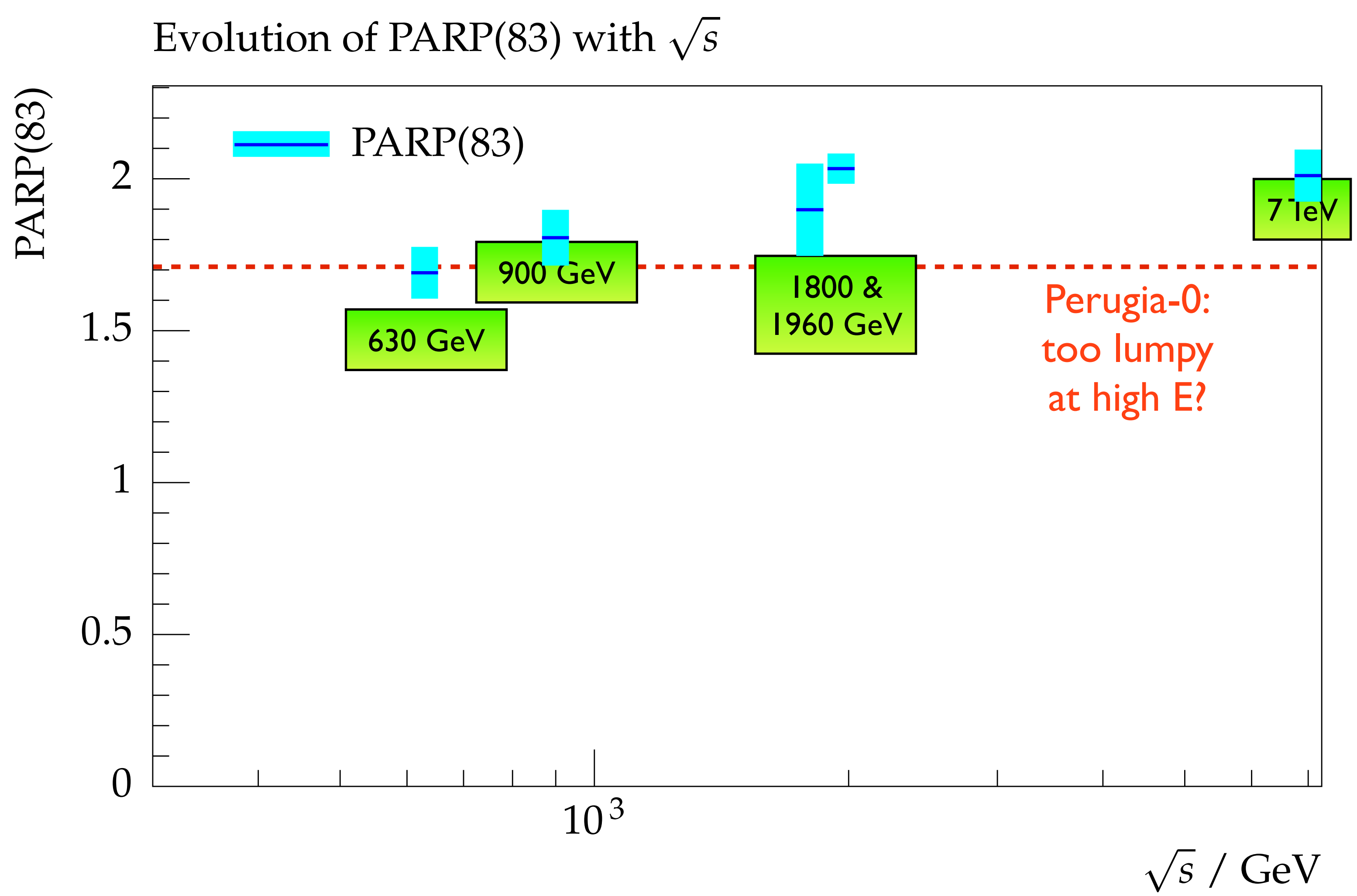
"Energy Scaling of MB Tunes", H. Schulz + PS, in preparation

Mass Distribution

Independent tunings compared to Perugia 0

Hint of departure from Gaussian *(PARP(83)=2.0)* at lower E_{cm}?

Consistent with higher average *x* at lower energies → more lumpy?



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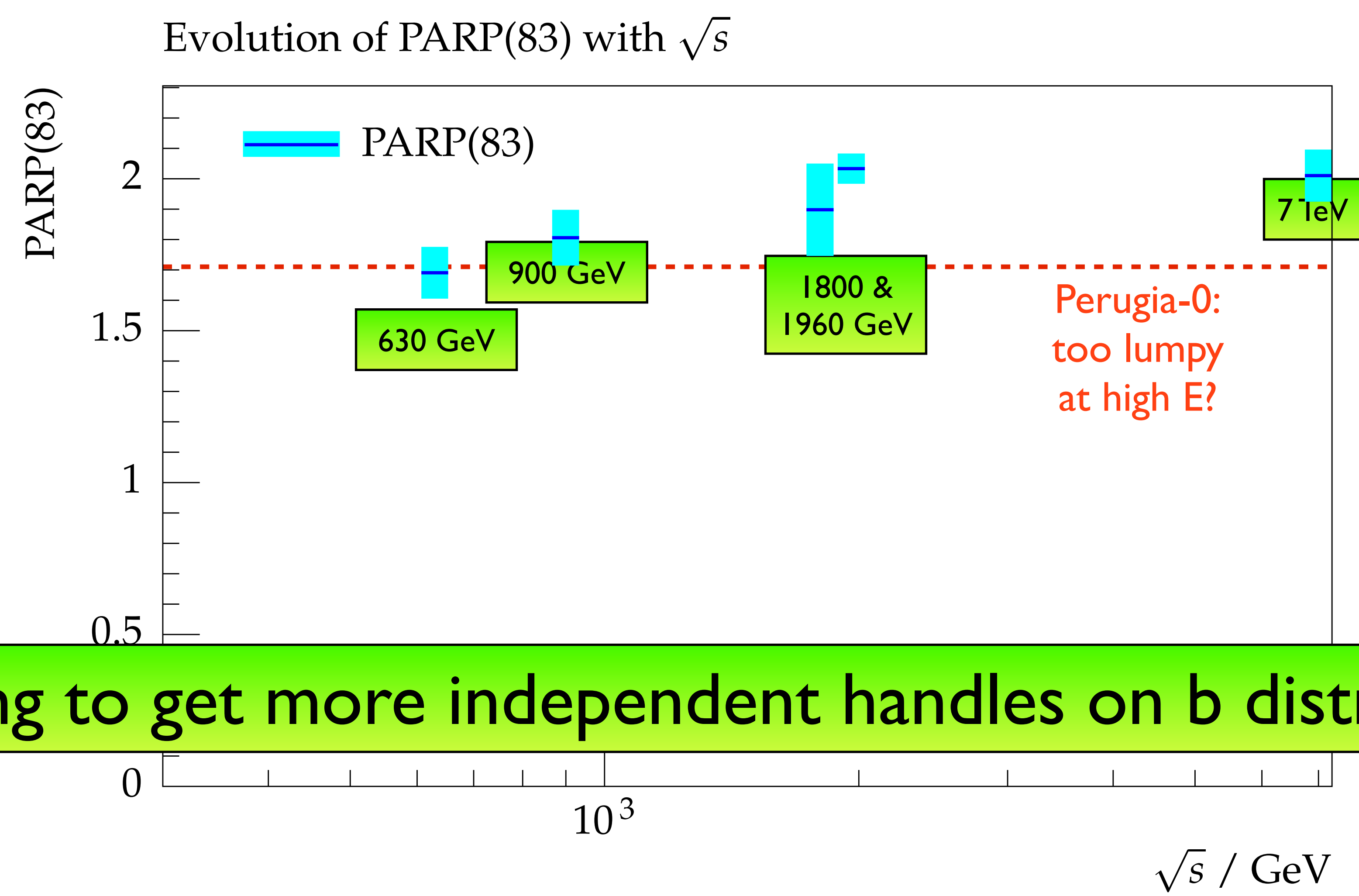


Interesting to get more independent handles on b distribution

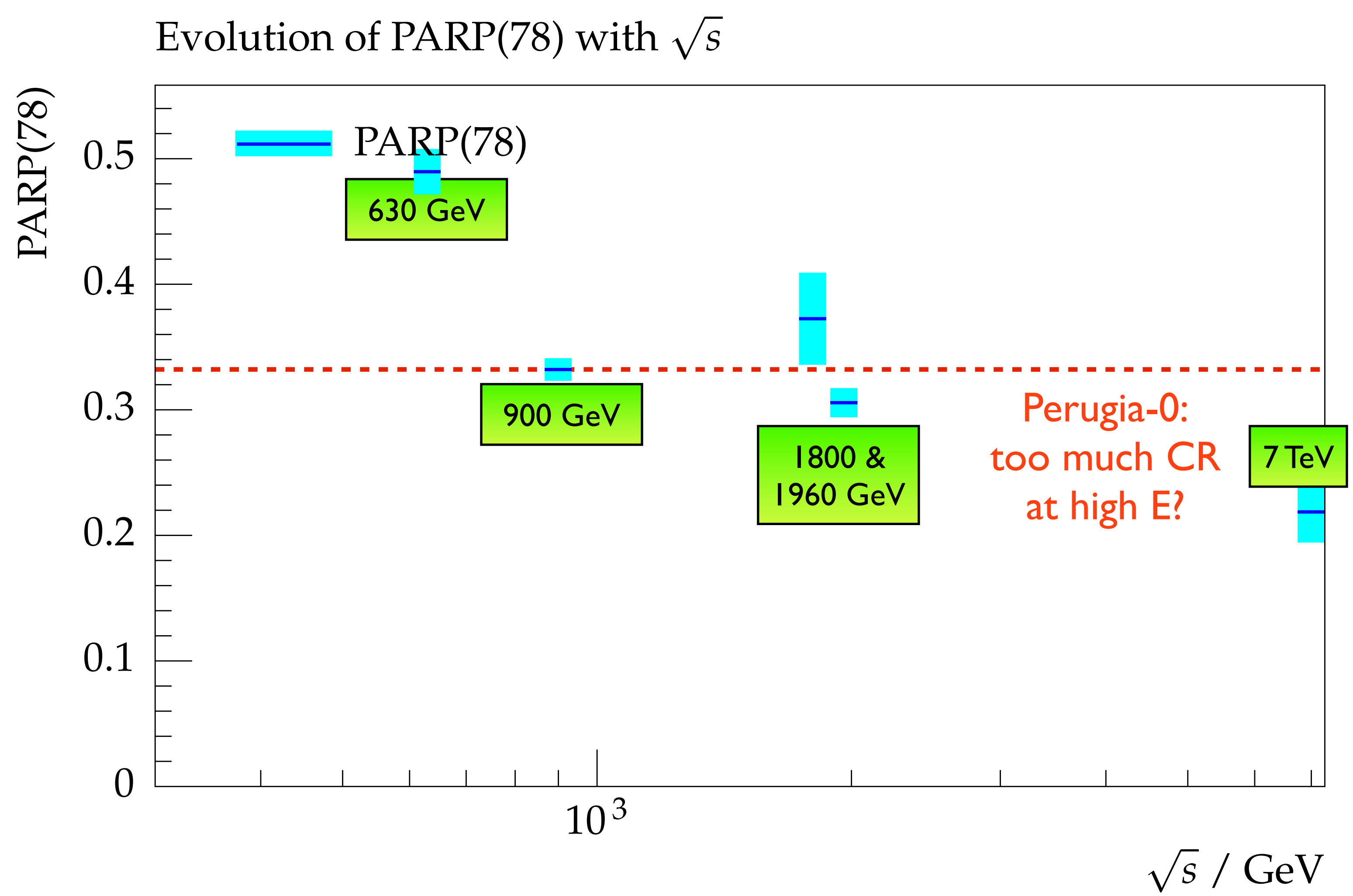
"Energy Scaling of MB Tunes", H. Schulz + PS, in preparation

Color Reconnections

Independent tunings compared to Perugia 0

CR are the most poorly understood part of these models

Assumption of constant strength not supported by data!



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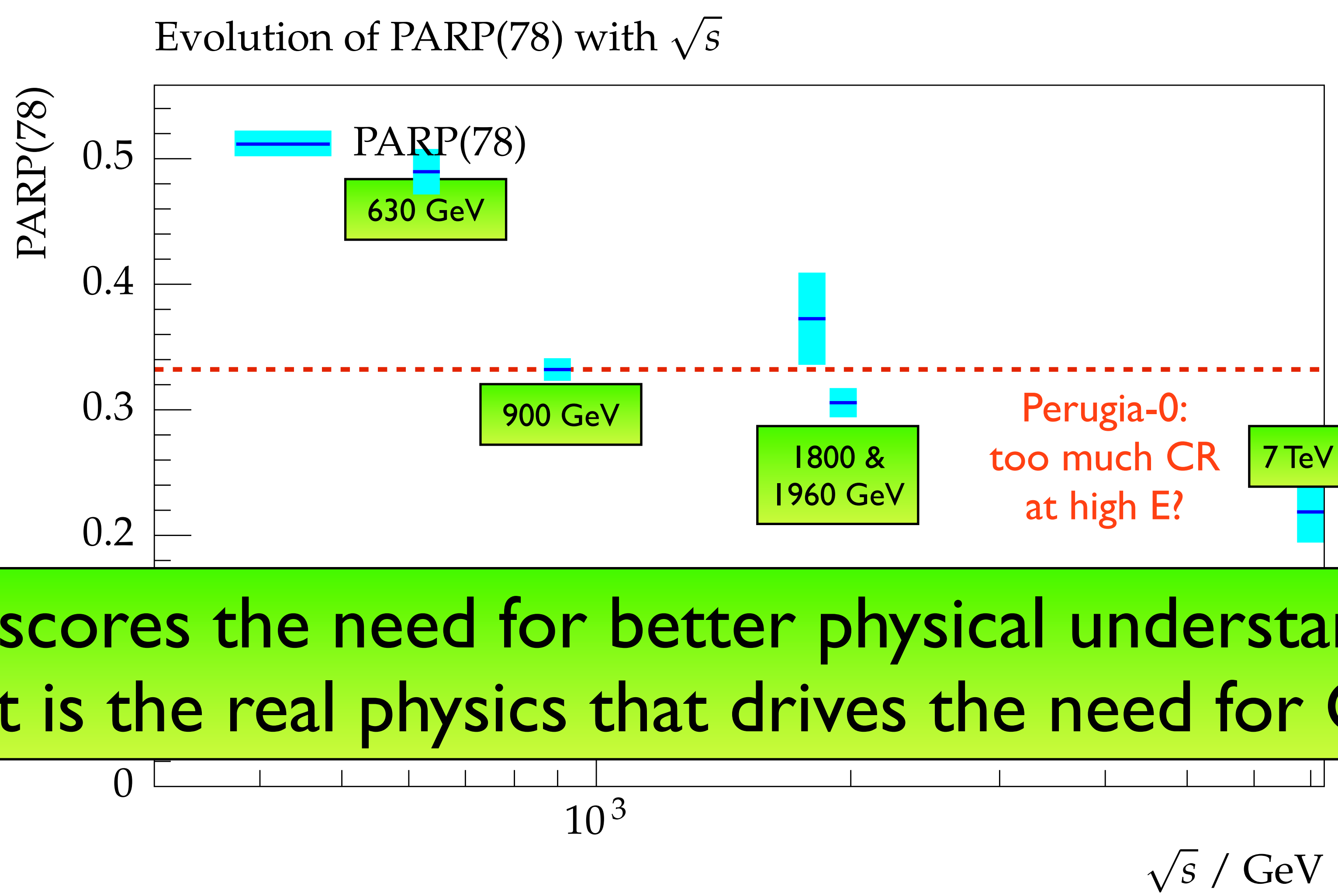


Underscores the need for better physical understanding
What is the real physics that drives the need for CR?

"Energy Scaling of MB Tunes", H. Schulz + PS, in preparation

Summary

A new way of using tuning tools

→ Check of consistency and universality of the model

Not just the best tune

Power + Flexibility of automated tools allow
independent optimizations in complementary phase space regions

We used different beam energies as our complementary regions
(→ tests of energy scaling assumptions)
Other complementary sets could be used to test other aspects

Crucial: Need complete and comparable data sets in each region!

+ get a data-driven idea of any non-universalities as a bonus → better uncertainties

More to learn about the physics behind Color Reconnections …

Backup Slides

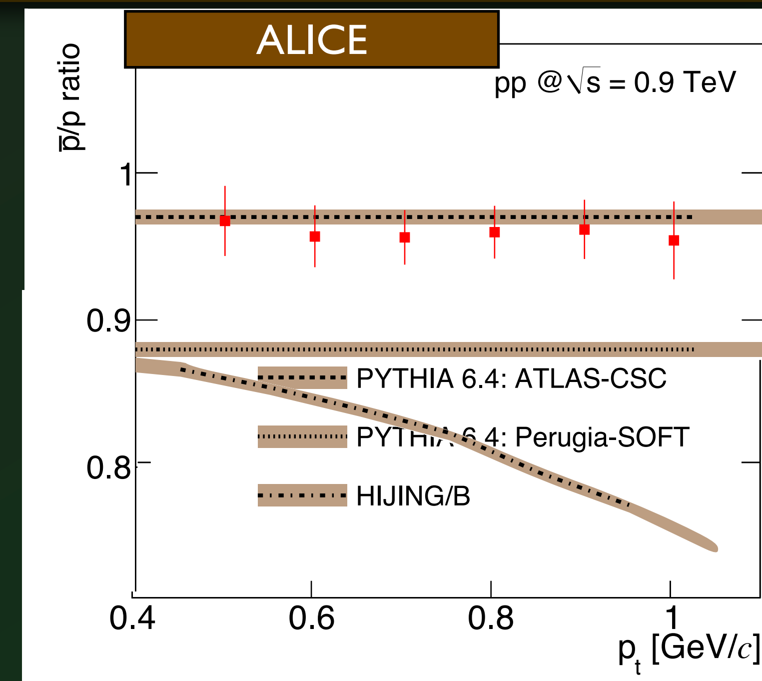
Baryon Transport

LESS than Perugia-SOFT

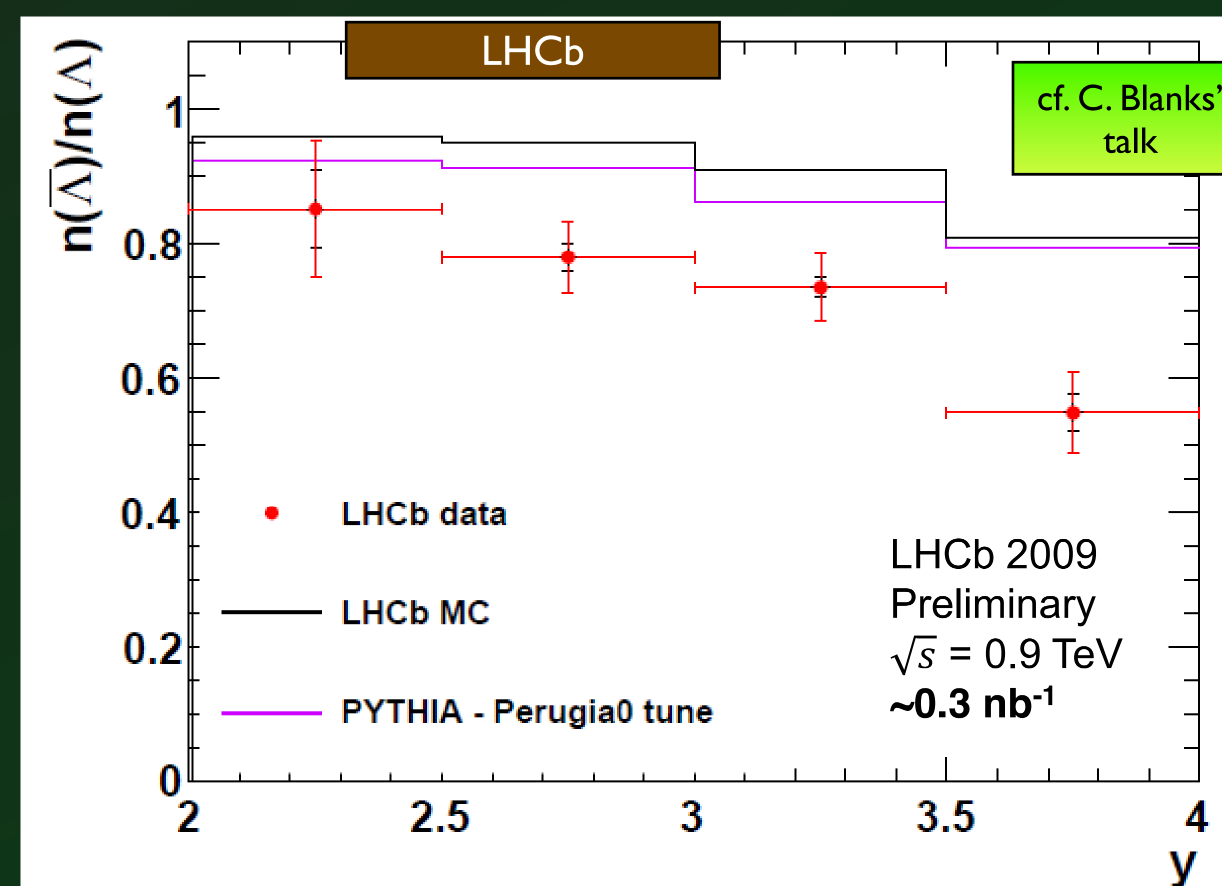
(at least for protons, in central region)

But MORE than Perugia-0

(at least for Lambdas, in forward region)



cf. J. Fiete's talk



cf. C. Blanks' talk

PYTHIA Updates

with input from R. Corke, T. Sjöstrand

PYTHIA 6

The Perugia Tunes

PS, arXiv:1005.3457v2

- Intended to provide reasonable starting points for tuning efforts of the p_T-ordered framework
- Mark the last development effort from the authors

Diffraction

- Obsolete Model: no diffractive jet production

→ PYTHIA 8: S. Navin, arXiv:1005.3894

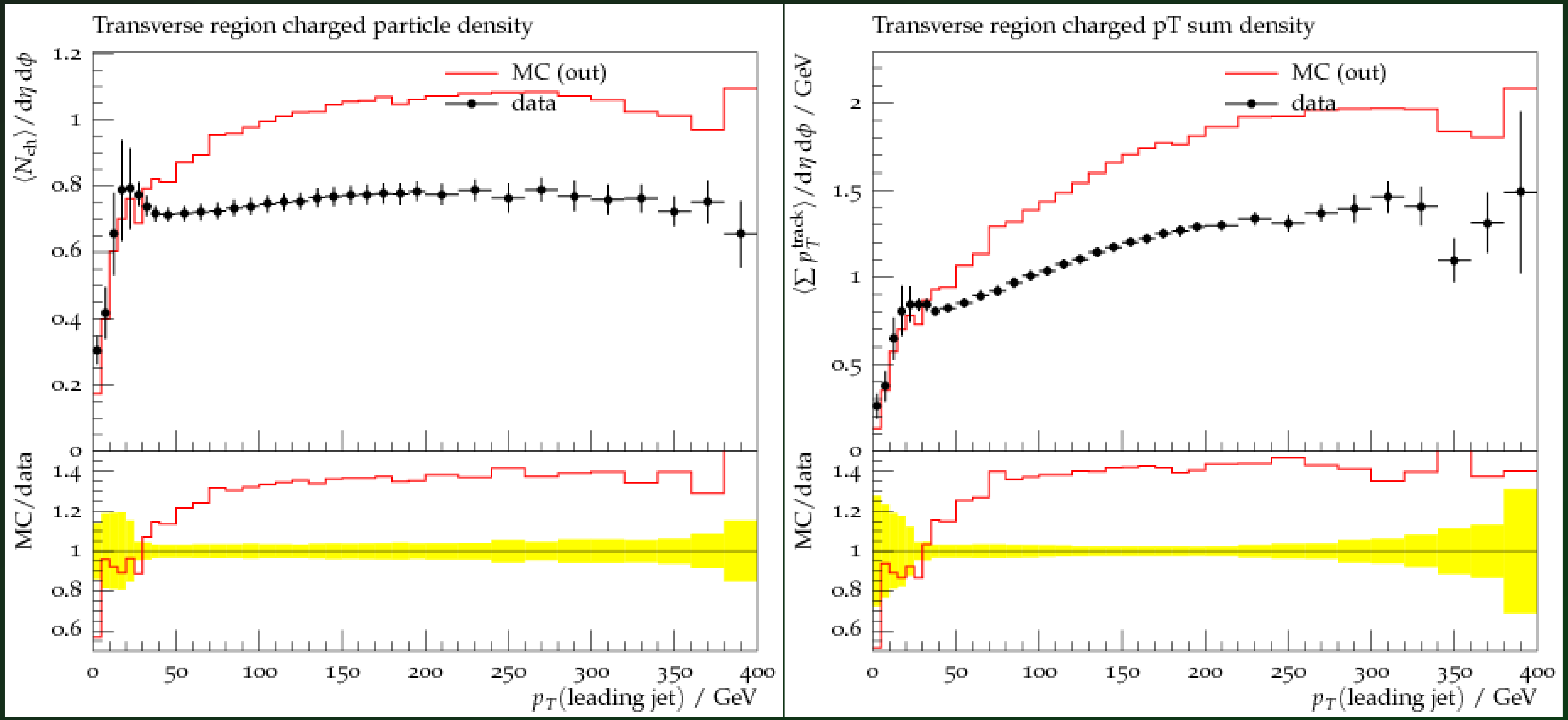
Status

- No longer actively developed

PYTHIA 8

cf., e.g., yesterday's ATLAS talk (L. Tompkins)

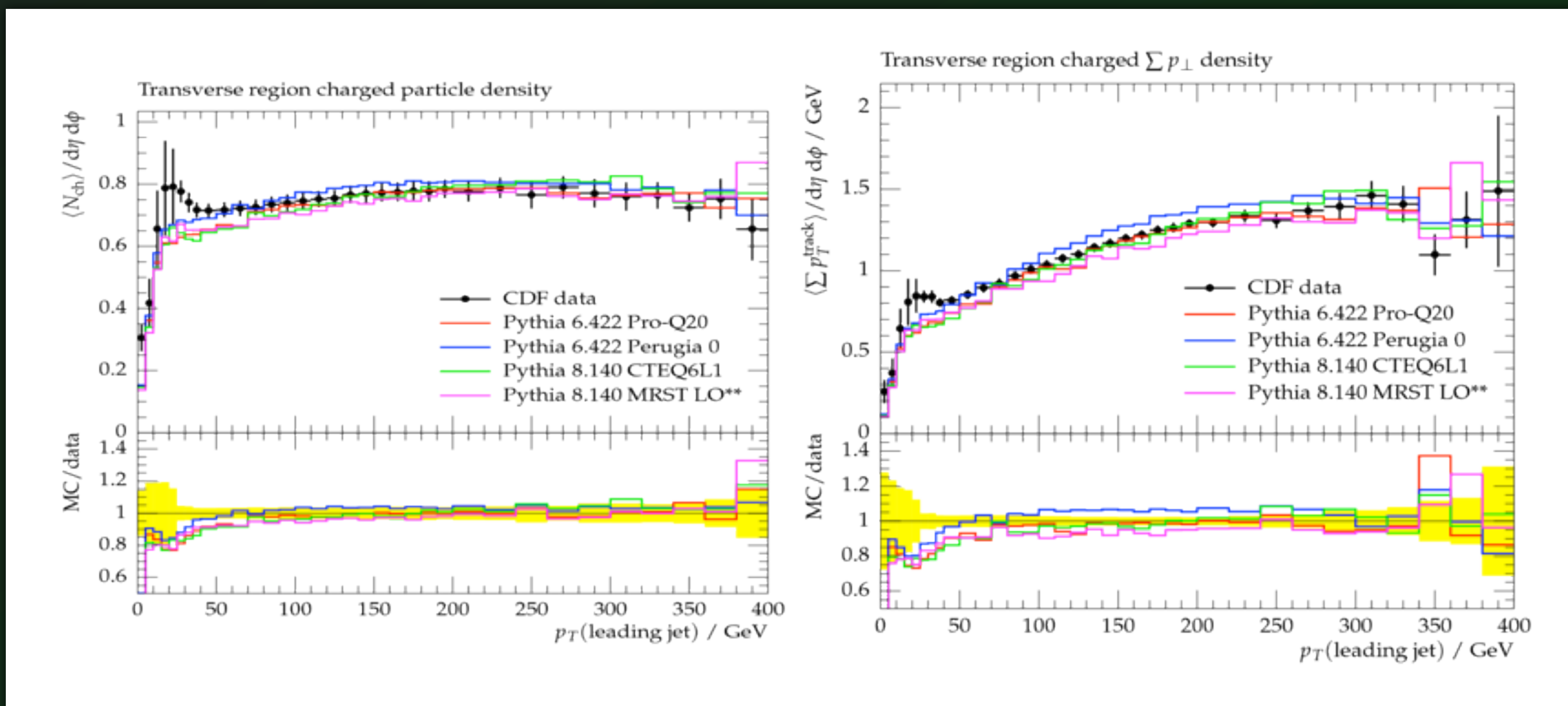
Already significant improvements but there was one snag...



Where did we go wrong?

A problem with Final-Initial Dipoles

(doublecounting), **now addressed →**



PYTHIA 8

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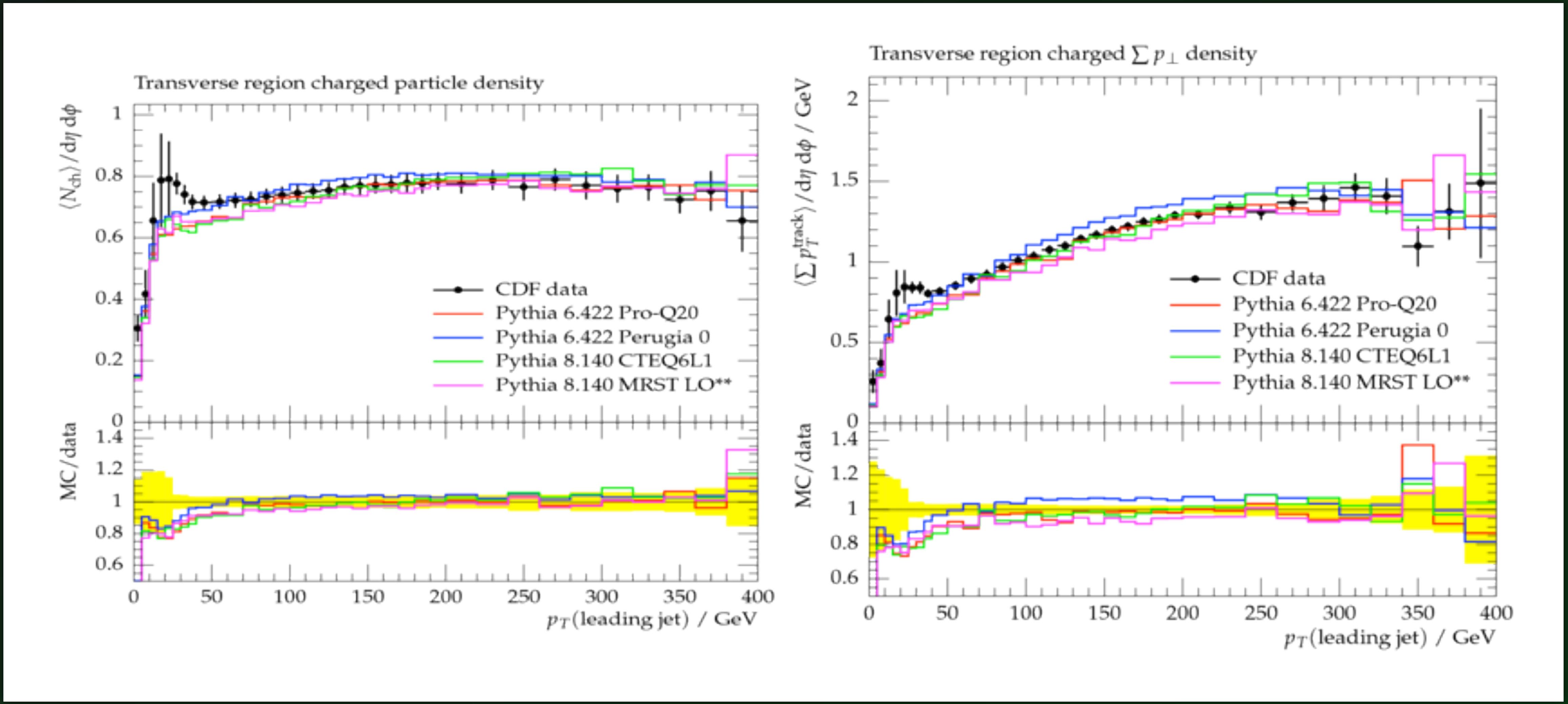
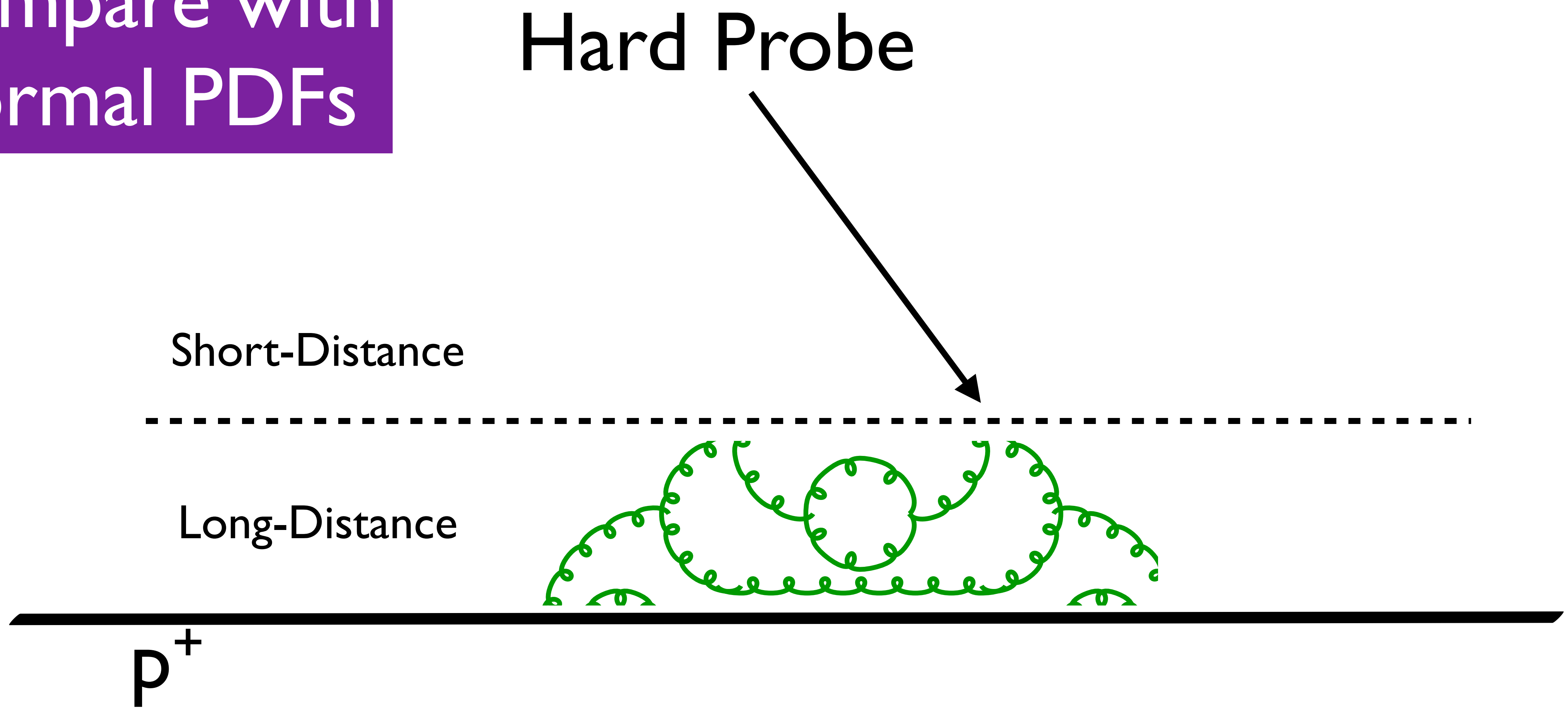


PYTHIA 8 now competitive with or better than PYTHIA 6 also for UE

(+ Diffraction)

"Intuitive picture"

Compare with normal PDFs



(+ Diffraction)

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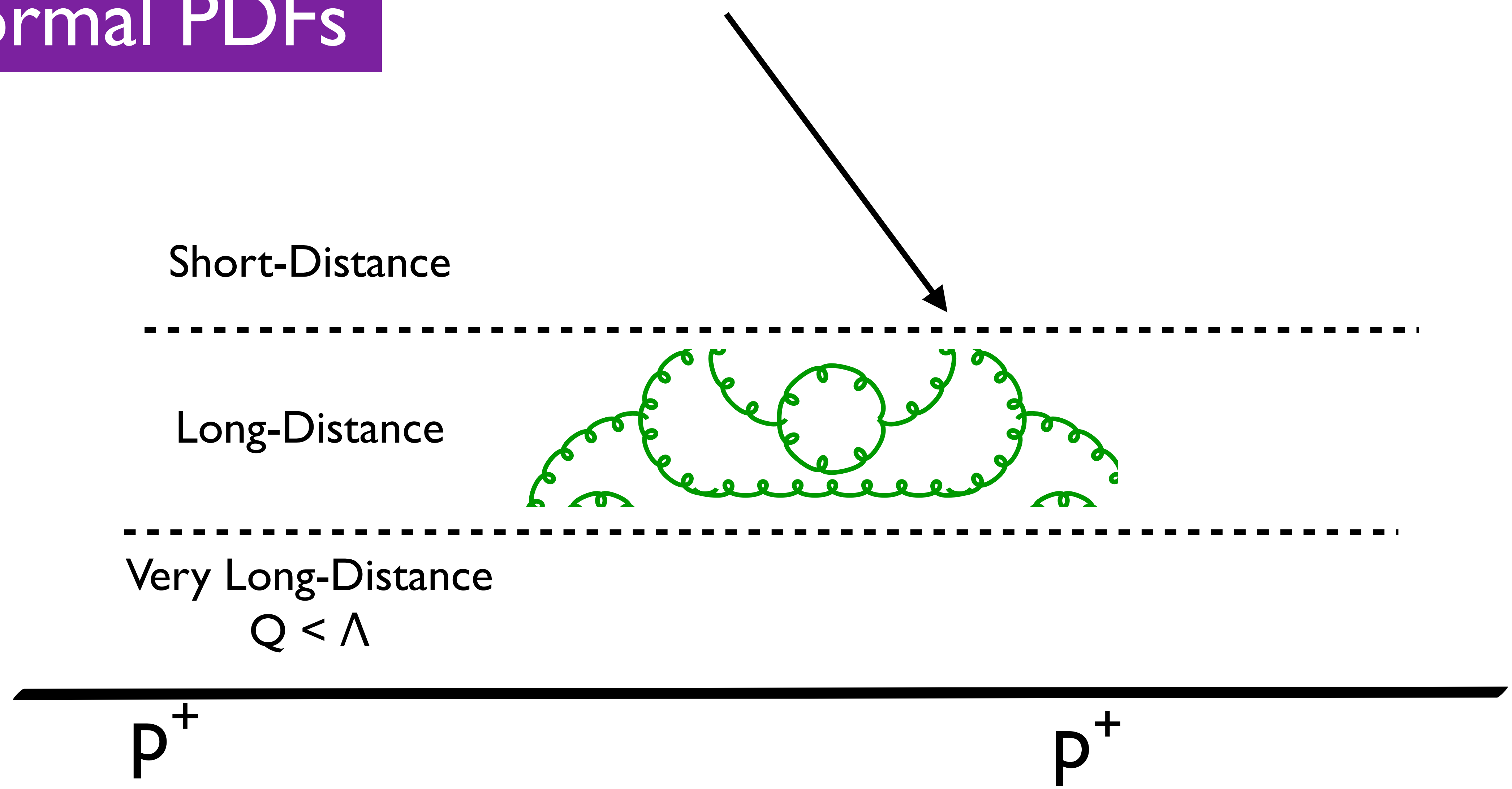

(+ Diffraction)

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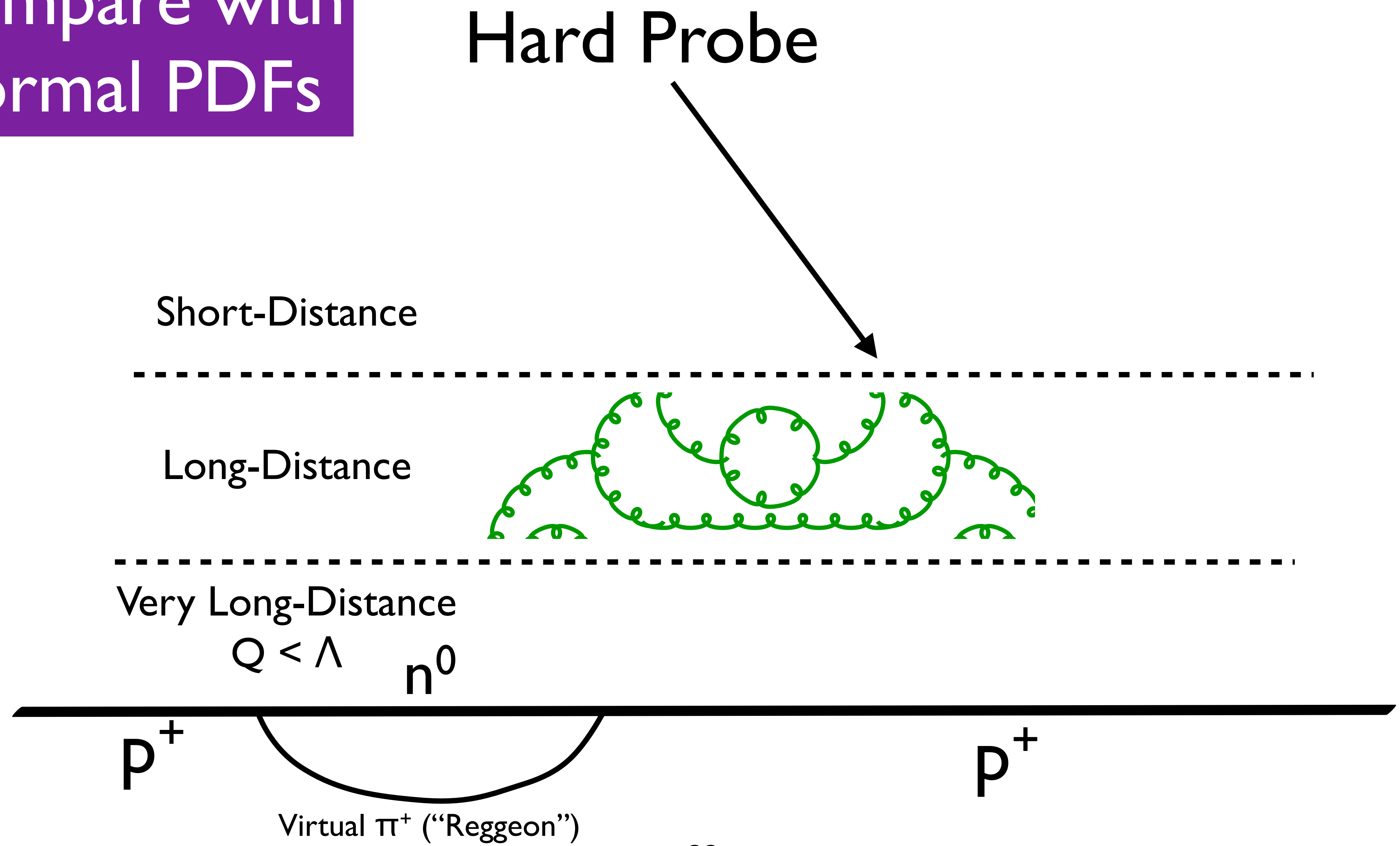
Compare with normal PDFs



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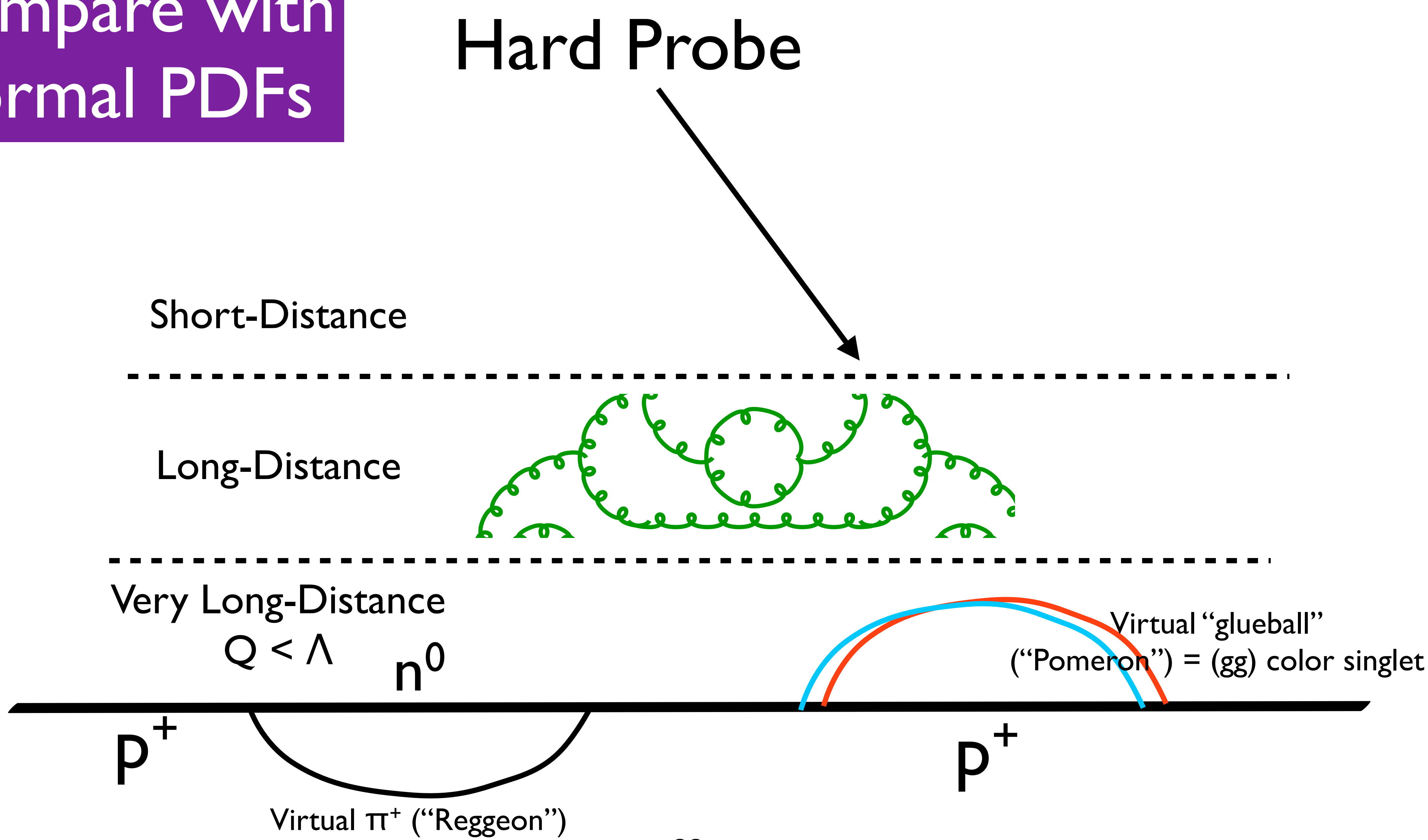

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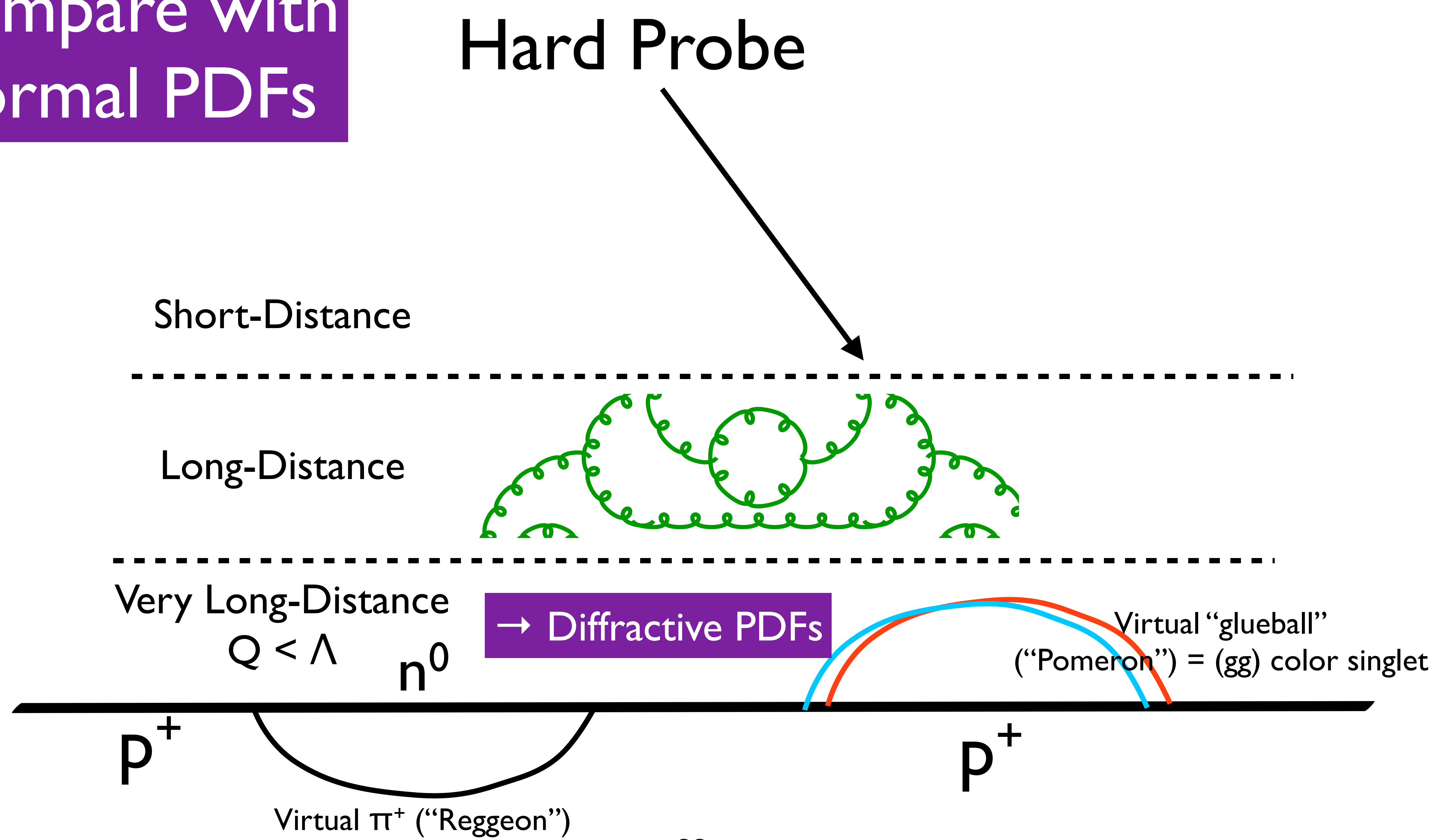

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